REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1959

COMMONWEALTH BUREAU OF SOIL INSTITUTE
9 JUN 1960

Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

1959

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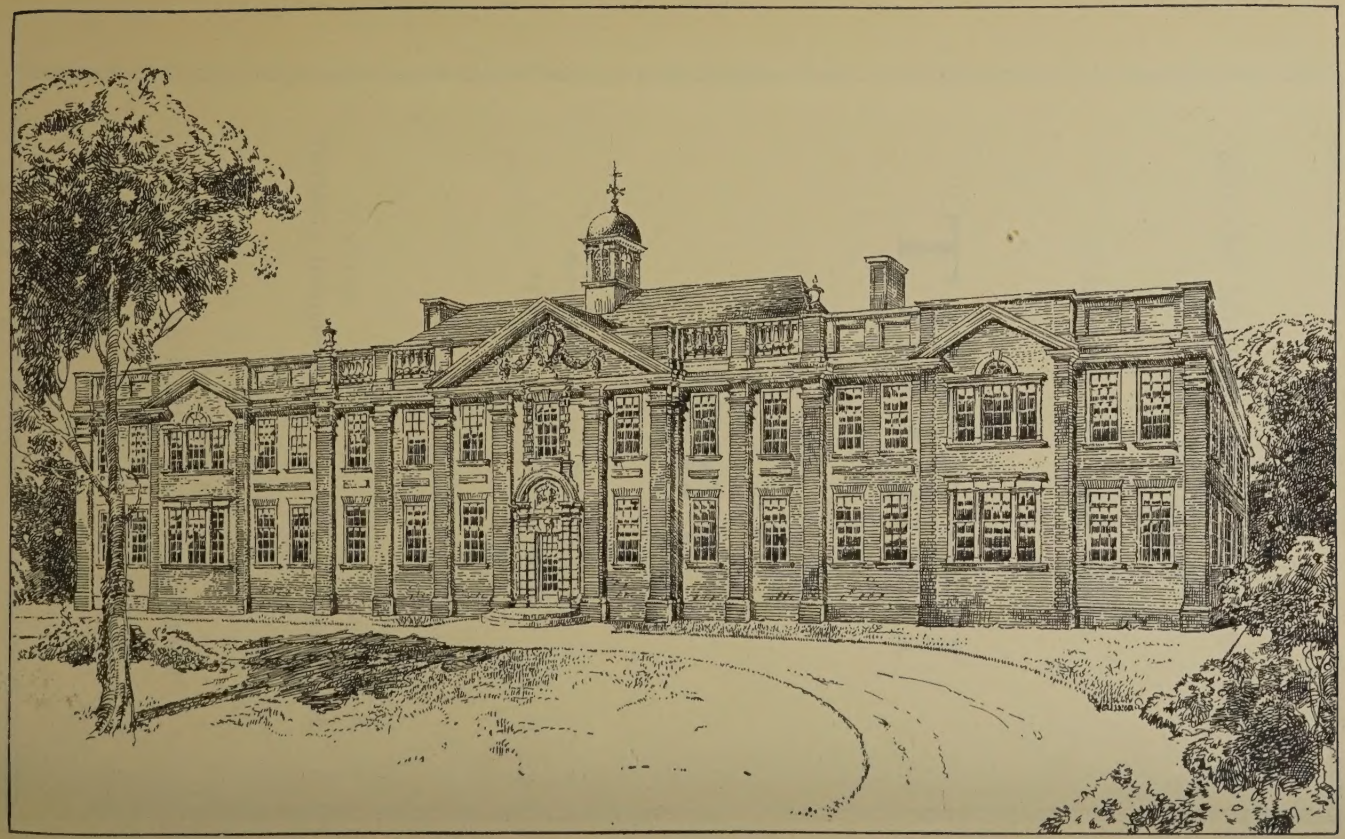

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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EDITH SPETCH, B.Sc.(Lond.)

The following spent varying periods as temporary workers at Rothamsted during 1959:

Australia: R. J. BEST (Plant Pathology and Biochemistry), A. H. GIBSON (Soil Microbiology), J. M. VINCENT (Soil Microbiology); **Belgium:** P. DAGNELIE (Statistics); **Ceylon:** L. A. S. PERERA (Bee); **Finland:** KATRI IKAHEIMO (Plant Pathology); **France:** J. GOURLET (Plant Pathology); **Germany:** E. KLAR (Soil Microbiology); **Ghana:** A. A. BRUNT (Plant Pathology), K. A. HAIZEL (Statistics), J. F. LONGWORTH (Plant Pathology); **India:** S. N. CHAKRAVARTI (Chemistry), S. P. MITRA (Pedology), R. C. SINHA (Plant Pathology); J. S. P. YADAV (Pedology); **Italy:** G. C. CHISCI (Statistics); **Japan:** M. KUSHIZAKI (Chemistry); **New Zealand:** J. N. PARLE (Soil Microbiology); **Nigeria:** B. O. E. AMON (Chemistry), C. M. H. ATKINS (Field Experiments), K. M. HARRIS (Entomology), C. L. M. VAN EIJNATTEN (Statistics); **Phillipines:** R. B. VALDEZ (Nematology and Plant Pathology); **Poland:** K. MICZYNSKI (Plant Pathology), MRS. WACLAWA D. POTAPCZYK (Botany); **South Africa:** H. D. BROWN (Entomology); **Spain:** P. ARAMBARRI (Chemistry), J. GARCIA-ALAMAN (Field Experiments); **Tanganyika:** J. W. VAIL (Pedology); **U.S.A.:** C. O. BERG (Entomology), F. A. BROOKS (Physics), B. S. MILLER (Entomology), M. SALOMON (Chemistry); **U.S.S.R.:** G. F. NAUMOV (Field Experiments), B. PLESHKOV (Chemistry), Y. A. RUSKO (Pedology); **British Isles:** P. BABOS (Plant Pathology), JANE BALSHAW (Nematology), W. B. BANAGE (Nematology), R. G. H. BUNCE (Plant Pathology), R. T. BURCHILL (Plant Pathology), SHEILA G. CAMERON (Biochemistry), HILARY R. CARR (Botany), C. CATEN (Plant Pathology), R. T. CLARKE (Statistics), JANE A. COCHRANE (Entomology), PENELOPE M. J. DEANS (Plant Pathology), ANN. V. DELAP (Botany),

Brenda J. Dodgson (Insecticides), Victoria Evans (Statistics), J. E. Gilby (Field Experiments), J. B. Gillespie (Soil Microbiology), G. N. Greenhaugh (Plant Pathology), Rachel Gregory (Botany), J. B. Hacker (Plant Pathology), S. A. Harris (Soil Survey), A. Jha (Plant Pathology), D. G. Jones (Soil Microbiology), J. King (Botany), Christine D. Maxwell (Botany), Gillian McMannus (Entomology), Anne V. Pickering (Bees), Anthea S. Potter (Bees), M. J. Reddy (Entomology), Rachel Reuben (Entomology), P. Roy (Biochemistry), Patricia Sanders (Insecticides), Anne Shelley (Entomology), A. C. Smith (Chemistry), Christine Smith (Plant Pathology), Miss M. I. M. Smith (Field Experiments), T. R. E. Southwood, (Entomology), M. J. Taylor (Entomology), Valerie Thain (Insecticides), D. P. H. Tucker (Chemistry), C. R. Turner (Insecticides), Helen G. White (Plant Pathology), Josephine H. K. Whittaker (Physics), M. S. Wolfe (Dunholme).

SOIL SURVEY OF ENGLAND AND WALES

Head of Survey

A. Muir, Ph.D.(Edin.)

Deputy Head of Survey

D. A. Osmond, Ph.D.(Bristol), A.R.I.C.

Soil Surveyors

G. D. Ashley, B.Sc.(Sheffield)
B. W. Avery, B.Sc.(Reading)
E. M. Bridges, B.Sc.(Sheffield)
P. Bullock, B.A.(Birm.)
C. P. Burnham, B.A.(Cantab.), B.Sc.(Lond.)
B. Clayden, B.Sc.(Sheffield)
W. M. Corbett, B.Sc.(Edin.)
C. B. Crompton, Ph.D.(Bristol)
A. Crompton, B.Sc.(Leeds)
D. C. Findlay, B.A.(Cantab.)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(For.)(Edin.)
C. A. H. Hodge, B.Sc.(Wales)
J. M. Hodgson, B.Sc.(Lond.)
R. A. Jarvis, B.Sc.(Dunelm)
D. W. King, B.Sc.(Lond.), A.R.I.C.
D. Mackney, B.Sc.(Bristol)
C. W. Montgomery, B.A.(Cantab.)
B. Plummer, M.A.(Wales)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
A. J. Thomasson, B.A.(Bristol)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.)(In Solomon Islands)
P. D. Jungerius, Ph.D.(Amsterdam)(In Ghana)
A. R. Stobbs, M.A.(Dunelm)(In Sierra Leone)

Chemists

C. L. Bascomb, B.Sc.(Agric.)(Reading)
Audrey M. Du Feu, B.Sc.(Lond.)
H. H. Le Riche, Ph.D.(Lond.)
D. T. Pritchard

Cartographer

D. V. Jones

Assistant Staff

R. Ball, Mrs. Joan K. Foster, Mrs. Muriel Green, P. G. Hoare, Marjorie D. E. Jackson, J. E. Knapp, Mrs. E. Joyce Mitchell, Margaret Roe, Sheila Smith, E. M. Thomson

Woburn Experimental Station

Officer in Charge

C. A. Thorold, M.A.(Oxon.), A.I.C.T.A.

Chemist

T. W. Barnes, M.Sc.(Lond.), F.R.I.C.

Assistant Staff

G. Pearce, Q. D. Pope

Dunholme Field Station

Head of Field Station

R. Hull, Ph.D.(Lond.)

Scientific Staff

S. N. Adams, D.Phil.(Oxon.)
W. J. Byford, B.Sc.(Lond.)
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R. A. Dunning, M.Sc.(Leeds), Ph.D.(Cantab.)
G. H. Winder, B.Sc.(Manc.)

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Agricultural Research Council Unit of Plant Morphogenesis and Nutrition

Head of Unit

F. J. Richards, D.Sc.(Birm.), F.R.S.

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J. R. Wilson, M.Sc.(Sydney)

Assistant Staff

W. S. Biggs, Priscilla M. Dutton, C. Sinclair, Mrs. Pamela J. Blanking

The Commonwealth Bureau of Soils

Director	G. V. Jacks, M.A.
Consultant Director ...	F. C. Bawden, M.A., F.R.S.
Assistant Director ...	W. D. Brind, B.Sc.
Assistants	G. A. Greenwood, B.Sc. Elizabeth E. Hardman, B.Sc. Mrs. M. Kathleen Milne, B.Sc. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Clerks	Sylvia P. Fletcher, Rita E. Hough, Mrs. Iris Lindsay, Marguerita D. Payne

The Bureau, one of ten Commonwealth Agricultural Bureaux, was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the two work together closely. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by giving technical assistance when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilisers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. The Bureau keeps itself informed on soil workers and their research, throughout the Commonwealth. Each Government nominates one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. Technical information is usually given free to soil workers.

INTRODUCTION

Sir John Bennet Lawes was experimenting before 1843, but the Rothamsted Experimental Station dates its foundation from this year because he then started his long and fruitful collaboration with J. H. Gilbert and laid down the classical wheat experiment on Broadbalk field. Lawes died in 1900 and Gilbert in 1901: they were succeeded as directors by A. D. Hall (1902–12), E. J. Russell (1912–43), W. G. Ogg (1943–58) and F. C. Bawden (1958–).

Until 1904, when the Society for Extending the Rothamsted Experiments was instituted, the work was paid for wholly by Lawes, at first directly and from 1889 from the fund of £100,000 with which he endowed the Lawes Agricultural Trust. In 1906 Mr. J. F. Mason paid for a bacteriological laboratory to be built, and in 1907 the Goldsmith's Company provided an endowment of £10,000. The first public money came in 1911 from the Development Commission, and since then government grants have been made annually; now the work is largely financed by annual grants from the Agricultural Research Council.

For long the experimental fields amounted to only about 50 acres, which were worked from the Rothamsted Home Farm, but in 1913 this farm of 250 acres was rented by the Station and the first farm buildings were put up on the site of the present range. In 1934 the Manor House, Home Farm, the site of the laboratories and various other parts of the estate, were bought by the Lawes Agricultural Trust for £35,000, raised entirely from voluntary subscriptions. Since then some additional land and other houses have been acquired, and the total area now owned is 580 acres, of which about 300 are suitable for field experiments. In 1952 the Manor House was opened as a hostel for members of staff and visitors.

The need to do field experiments on a range of soil types was early recognised, and since 1921 experiments have been done at many places away from Rothamsted. The taking over in 1926 of the Woburn Experimental Farm, which had been run by the Royal Agricultural Society of England, allowed experiments to be made simultaneously on heavy land at Rothamsted and light land at Woburn. In 1947 work on diseases of sugar beet became a part of the station's activities, and this has now developed into the Dunholme Field Station, Lincoln, at which the pests and manuring of sugar beet are also studied.

Although a range of problems was studied before 1900, the work was mostly chemical, and only few workers were engaged. With increasing numbers of staff in the early 1900s, the activities also widened and Departments of Botany, Soil Microbiology and Physics separated from the original Chemistry Department before 1914, and soon after the end of the First World War new Departments of Entomology, Plant Pathology, Insecticides and Fungicides, and Statistics were started. Except for additional posts for work on bees and on viruses and virus diseases, the Station's activities then

expanded little until the Second World War, when most Departments increased in size and others were added for Pedology (1945), Biochemistry (1947) and Nematology (1947). In 1946 Rothamsted also became the headquarters of the Soil Survey for England and Wales. From a total of 28 in 1912, the staff increased to 140 in 1943 and 471 in 1958. The Commonwealth Bureau of Soils, one of the ten bureaux that act as clearing centres for information on agricultural science, has been housed here since its establishment in 1929, and the Agricultural Research Council Unit of Plant Morphogenesis and Nutrition, previously the Research Institute of Plant Physiology, has a laboratory and glasshouses at Rothamsted. The Station also accommodates visiting workers, many of whom use the special relationship with London University to register as internal students of the university for research degrees.

The building of laboratories, glasshouses and other ancillaries has roughly paralleled the growth of staff, but has always lagged behind, so that at least some of the departments are always overcrowded and the number of visiting workers that can be accepted is always much smaller than the number of applicants. Of the existing laboratories, the main block is the oldest and was opened in 1919; the North Building dates from 1924, the South Wing from 1940, the Nematology Building from 1947 and the West Building from 1955.

The Library

Until 1913, when Sir Henry Gilbert's books were given to the Station by his widow, the Library consisted almost entirely of Sir John Lawes's collection. It then grew rapidly in size and scope, until in 1917 it contained 10,000 volumes and in 1958 about 60,000 volumes. Its stock includes about 3,500 agricultural books published between 1471 and 1840, of which 13 are incunabula; 5,000 serial publications—1,700 of them current; 100 MSS. from the 13th century onwards, in addition to the Lawes and Gilbert papers; about 300 maps; and nearly 1,000 prints of livestock, mainly of the 18th and 19th centuries.

The following catalogues have been published: of serial publications (1954), of early agricultural books (1926, second edition 1940, supplement 1949) and of livestock prints (1958). The *Quarterly bulletin of the International Association of Agricultural Librarians and Documentalists* (1956–) is edited and published in the Library.

GENERAL REPORT

F. C. Bawden

Broom's Barn Farm, about 200 acres of light land, at Barrow, midway between Bury St. Edmunds and Newmarket, was bought in September with money from the Home Grown Sugar Beet (Research and Education) Fund after it became obvious that tenure of the Dunholme Field Station could not be secured. As soon as laboratories have been built and other essentials provided, the staff now at Dunholme will move to Broom's Barn.

At Rothamsted some land was given up temporarily by the lease of Baldwin's Paddock to the Ministry of Agriculture for 99 years as the site of their new Plant Pathology Laboratory, which now graces the Hatching Green entrance to the farm. We extend a cordial welcome to our tenants, wish them every success in their new surroundings and add that we look forward with pleasure to even closer collaboration than before.

H. V. Garner retired from the post of Head of the Field Experiments Section on 31 March and was succeeded by G. V. Dyke. Fortunately we still benefit from Garner's wise advice and his unrivalled knowledge of the field experiments, for he continues to be employed part-time.

F. Tattersfield, who worked at Rothamsted from 1918 to 1956 and was Head of the Insecticides and Fungicides Department until 1947, died on 1 May. His influence was great and will long survive him, not only at Rothamsted, where he pioneered the study of insecticides, but the world over, for he can truly be called the father of the subject. The memory of him as a person will also long remain with the many of us to whom he was a valued friend. A true scientist, whose interest and curiosity in all natural history remained undimmed with age, he did productive research almost until he died.

J. M. Hirst had the signal honour of being the first recipient of the Jacob Erikkson Gold Medal, awarded at the International Botanical Congress for outstanding work of international importance in plant pathology and mycology. Unfortunately he could not be at Montreal, and we thank Mr. M. J. Marshall, the United Kingdom Trade Commissioner, for publicly accepting the medal on his behalf. P. S. Nutman was awarded the Huxley Memorial Medal, given to former students of the Imperial College of Science and Technology for their research in natural science. G. W. Cooke was awarded the silver cup for the best paper—"Fertilisers, Crop Production and Soil Fertility"—read to the Farmers' Club. F. C. Bawden was elected an Honorary Life Member of the New York Academy of Sciences.

Again we welcomed many visitors from home and overseas. How many we do not know, for not all are recorded, but our records show 3,140 individuals. Among those from overseas were the Director General of the Food and Agriculture Organisation, Mr. B. R. Sen; the Ministers of Agriculture for India, Mr. S. K. Patil,

for the Western Region of Nigeria, Chief Akin Deko, and for Pakistan, Mr. Hafizar Rahmann; and the Minister of Research and Information for the Nigerian Federation, the Hon. Victor Mukete.

As the departmental reports show, several of our staff also travelled overseas for a variety of purposes. Our largest contingent was at the Botanical Congress, and we thank the Canadian organisers for the compliment they paid us in inviting so many of the staff and for their generosity in paying for four of the seven who attended.

The weather and farming

A greater contrast between 1958 and 1959 could hardly be imagined. Typical of the difficult conditions of 1958, we entered 1959 with only part of Broadbalk drilled and most of the other land destined for winter wheat still untilled. But with the new year things rapidly improved, and arrears were soon made up, with the spring corn drilled almost immediately after the delayed winter-wheat varieties. As things started, so they continued; conditions for harvesting all crops, hay, cereals and roots, were ideal, and the only major difficulties were a shortage of grass for the stock in the late summer and ground too hard to plough in autumn. A vivid comment on the two years is that all cereal experiments at Rothamsted were harvested in 1959 by the date when the first plot was cut in 1958. We enter 1960 with winter wheat well above ground on all Broadbalk plots and on many other fields, both at Rothamsted and Woburn.

We shared with the rest of the country the sunniest summer for years, but did not fully share the drought. At Rothamsted, and to a lesser extent at Woburn, many of the crops benefited from intense local storms. On 10 July, 2·3 inches of rain fell at Rothamsted, and further heavy falls brought the July total to 4·5 inches, 2 inches above the average, and the seven-months' total to 15·5 inches, 0·3 inch above the long-period (106 years) average. All months April to October inclusive had from 10 to 40% more sunshine than average, and mean monthly temperatures were from 1·6° to 4·7° F. above average. The wet July was the sunniest month since July 1935 and the warmest July since 1949.

Although the drought was less severe at Woburn than many other places, responses to irrigation there were large. Yield of sugar beet was increased by 50%, of spring wheat by 60%, of grass by 100% and of spring beans by 150%; the irrigated beans grew so high that they over-topped the spray lines!

At Dunholme, where only 6·5 inches of rain fell between January and October, the sugar beet suffered severely from drought, which also caused a few experiments at other centres to fail. Where soil moisture was adequate, however, yields were exceptionally high, 30 tons/acre of roots and 5·2 tons of sugar at Pondersbridge and 28 tons of roots and 4·5 tons of sugar at Holbeach. The weather favoured aphids and the spread of yellows, which would have caused great losses had not insecticidal sprays been used on an unprecedented scale. Warnings of the need to spray were issued from Dunholme as the number of aphids reached the danger level in different districts, and more than 95% of the total beet acreage was sprayed once, and much of it more than once. The response to

spraying differed in different places (in some yield was doubled), but the results from widely scattered experiments suggest that average yield was increased by 25%. A remarkable achievement for a scheme initiated only in 1957.

The range and aim of research

The work on which we report this year covers an even greater variety of subjects than previously, ranging from attempts to derive an international language for computers to homely recipes for serving leaf protein, and from the isolation of " queen substance ", by which the queen bee largely controls the activities in the hive, to measuring the current value of manures added to land last century. The ultimate aim of agricultural research must, of course, be to increase the efficiency of agriculture, that is to lower unit costs of production by increasing yields per acre, per man or per sum of money spent, and to improve the quality of the produce. That the work summarised in the departmental reports on such things as fertiliser use and the control of pests and diseases has this as an immediate rather than ultimate aim is too obvious to be worth comment, but the practical implications of work that at first sight may seem to be academic or esoteric can also be considerable.

True, few farmers are themselves likely to use an international language for computers, but this does not mean that to develop one would not benefit agriculture. The success of our computer, which shows in the great annual increase in number of analyses made, makes it certain that more and more computers will be used to analyse the results of experiments and surveys. Unless an international language is developed, new programmes will have to be prepared for each type of computer, which will need much time and labour and delay the appearance of results.

Nor are many people likely immediately to abandon Mrs. Beeton's recipes in favour of ours for serving leaf protein. However, if the expected growth of the human population leads to protein becoming increasingly scarce and dear, we are now provided, not only with a method of getting much more per acre than from meat or milk, but with the knowledge that it can be served palatably.

To know the identity of such biologically important and specifically active materials as " queen substance " and eelworm " hatching factors " is information more than worth having for its intrinsic interest alone, but the knowledge could also lead to practical uses. Identification is a necessary step to synthesis, and a cheap synthesis of these substances could lead to new methods of handling bees or dealing with eelworms. Again, although most farmers are probably more interested in knowing what return they will get from fertilisers than in the status of their soils 100 years hence, agriculture is an industry that must continue indefinitely, and nothing could be nationally more important than to know what practices increase and what practices decrease the fertility of the soil. The long-term experiments at Rothamsted and Woburn provide a series of soils unique in the amount of information they now contain about the effects of different kinds of manuring, but much of the information is latent and will become apparent only when the experiments are

modified, as they increasingly must be, to answer new questions of agricultural significance.

Our work has to be diverse, because agriculture is varied and raises an unending series of interacting problems, with each new practice bringing new consequences in its train. In other industries a discovery made anywhere is likely to apply everywhere, but this is far from being generally true in agriculture. Crops are grown on a great variety of soils and in widely different climates, and a practice proved to be beneficial in one place is by no means certain to be beneficial everywhere. The empirical approach can be very successful and sometimes quickly produces answers to practical questions, but alone is wholly inadequate for the needs of agriculture. To forecast whether a practice found beneficial somewhere has general use requires knowledge about how it works, which entails establishing principles. Until the principles that underlie the problems of soil fertility and the use of fungicides, pesticides and herbicides are much more firmly established than they now are, recommended practices will sometimes fail and will occasionally have undesirable consequences.

The value of the soil survey, which this year changed to a less detailed, reconnaissance type, so that much more land was mapped than in previous years, will also not be fully realised until knowledge increases about the soil conditions that determine whether potential plant nutrients move into or out of states in which they can be acquired by plants. The survey now provides many answers to practical problems, not only in agriculture but in other industries and in town-planning, but we look forward to the time when knowledge is such that a soil map used in combination with a knowledge of recent cropping and manuring will provide a sound basis for deciding fertiliser needs. It is to this end that the detailed structure and composition of soils are studied and better methods than current ones are sought to assess what proportion of the plant nutrients they contain will be usable by crops. We have this year made some advances, of which perhaps the new information on potassium is specially noteworthy. The amount of potassium that a soil can provide immediately to a crop is normally measured by the amount that will exchange with another cation when the soil is treated with a salt solution. However, many soils will provide much more potassium than this method measures, but the only method of identifying such soils has been to grow crops on them. The analysis of a range of soils shows that their content of useful but not exchangeable potassium is related to two qualities, the amount of fine clay (particles smaller than 0·3 μ) and the potassium content of these fine clays. Presumably the explanation is simply that fine clay exposes a larger surface area than coarse clay from which potassium can be released.

Research work is sometimes described as the asking of questions, with success depending on asking the right question. Sometimes, not only are the questions that need to be asked obvious enough, but so are methods of getting answers that may be practically useful. For example, when a crop is obviously sick, the first question must be, is it being attacked by something or does it lack something? When the cause is diagnosed, possible control measures, either cura-

tive or preventative, may come directly from existing knowledge about comparable problems. But such a happy state of affairs is rare; although the right questions may be asked, and valid answers obtained, the answers often fail to have any immediate practical application. Even when a research worker considers a practical answer has been found, not all farmers will necessarily agree. For instance, although it may be established that a given rotation of crops will avoid or alleviate damage from a given soil-borne pest or disease, a farmer engaged mainly in cereal growing cannot readily change to other things, and one whose livelihood comes from potatoes cannot lightly abandon this crop. A problem has been solved for the farmer who can rearrange his plans so that susceptible crops are grown no more often than the research worker would advise, but such farmers may well be a minority. Research cannot stop at this stage, for although partial success is a good deal better than nothing, it is also partial defeat simply to withdraw in the face of the enemy. A maker of blankets troubled with moth in his wool would not consider his trouble solved by someone who advised him to change his business over to cotton sheets. Similarly, although advice to change crops is now often all that can be given, and in want of anything better valuable advice it is, the prominent part pests and diseases now play in determining crop rotations can only be regarded as temporary and as a challenge. The challenge is to find knowledge whereby farmers may safely grow the crops of their choice and not those forced on to them by the need to avoid pests and diseases.

The use of immune or resistant varieties is one response to this challenge, and our work with *Fusarium* wilt of peas suggests that growers troubled with this disease will gain relief by changing to other varieties. But before resistant varieties can be produced, the plant breeder must have a supply of resistant parents from which to breed, and for many of our pests and diseases there are no such things. Even when there are, the relief given by producing a resistant variety may be only temporary, for pests and diseases are variable things, and often soon change to forms that attack previously resistant varieties. It is idle to look for any panacea or for any permanent solution; the price of healthy crops is eternal vigilance, which means continuous study of the biology of pests and diseases and the physiology of the crop to know where and when the parasite can best be attacked, and what properties of the crops are likely to continue to protect them from damage.

Correct diagnosis of troubles does not lead automatically to remedial measures, even to those that might satisfy a research worker. Such measures may have to wait for new knowledge, which sometimes comes from unexpected quarters. For over 30 years King Edward potatoes have been known all to be virus-infected. Although there has been no evidence that infection with this particular virus affects yield (there could be no such evidence without any virus-free plants for comparison), it was obviously desirable to have a virus-free stock. But how to get one was less obvious until work on the distribution of viruses in infected plants suggested that the growing points of stems might contain no virus. Apical meristems were then excised from King Edward potatoes, nurtured on

agar medium until one grew into a plant, which was indeed uninfected, and the progeny of which is now being rapidly propagated. Whether this clone will yield better than those now in commerce, only time will tell, but it shows promise. Again, sugar beet yellows has long been known to be caused by an aphid-transmitted virus with the clear inference that a suitable insecticide might control it, but this knowledge was in the academic category until there were suitable insecticides. After the great increase in yields this year from spraying, to criticise current insecticides adversely seems almost churlish, but it is true that yellows was still only partially controlled. Work must still continue, to find either more effective insecticides or another method of control, and meanwhile the practice of spraying such large areas with current insecticides also needs careful watching.

In doing research, particularly in the laboratory or glasshouse, conditions can often be simplified so that individual problems can be studied on their own, but this simplification is impossible in the field, where the consequences of any treatment put into practice must always be tested in the widest possible context. The chances of unwanted side-effects are perhaps most apparent with the use of insecticides, which carries with it the double hazard of mammalian toxicity and of killing insects beneficial to agriculture. However, the fact that these hazards are so obvious itself provides some safeguard, for they cannot be neglected. Insecticides, and other pesticides, will be increasingly used, because agriculture cannot forgo the benefits they confer, but this carries with it the obligation to know as much as possible about the ways in which they kill and their effects on animals other than those they are immediately directed against. Work on the mechanism of insecticidal action aims not only to increase the kill of pests but also to increase specificity, so that only pests will be killed. The effects of insecticides, too, provide part of the background to population studies of insects, both of pests and others, but only part, because insect ecology and biology also seeks knowledge that may help to defeat pests without the continued need to resort to chemical warfare.

The consequences of other agricultural practices are not necessarily fewer because they are less obvious than those of using pesticides. Whenever a new variety is grown on a large scale, or manuring, cultural practices or sowing dates alter, the environment of the growing crop changes and there is always the chance that a pest or disease previously trivial may now be favoured and become important. Good field experiments demand more than simply applying differential treatments to plots and measuring yields, even when the statistical design and analysis are excellent. They require repeated observation, with full knowledge of the soil conditions, of weather and of the incidence of pests and diseases. Without this information, there is simply a result, a measurement which may never be precisely repeated, whereas with it there might be a meaningful interpretation with general implications. Repeating experiments in many places or in many years is not only costly, but is no substitute for intensive research. It can give only average results, which are no doubt valuable for those who have to think nationally, but to the individual farmer may be no more use than are the average rain-

fall figures for telling him whether next August will be wet or dry. When a treatment can give widely different results at different times or places, there is little to be gained by testing it in repeated experiments that simply demonstrate this fact again. What is needed is a detailed study of the treatment to see how it works, to establish principles so that the conditions in which it will be beneficial can be precisely defined.

Forty years ago it was rare to record wheat yields of 1 ton/acre at Rothamsted, whereas we now sometimes record well over three. The difference has three main causes: better feeding, pests and diseases better under control, and higher-yielding varieties. The goal of a field crop optimally fed and watered and free from parasites has yet to be achieved, and potential productivity will remain uncertain until it is. However, there are clearly limits to the increases in yield possible simply by increasing health, and it is important to know whether there are other possibilities. Put as a question: what limits potential yields and can the limiting factors be overcome? The weather in winter is obviously important, because temperature and light intensity are for long periods below those needed for active photosynthesis. Also, frost-sensitivity or early maturation mean that some crops make little or no use of much favourable weather because their leaves are not yet developed or have already matured. But there are also other factors intrinsic to the plants, for different crops in the same conditions grow at different rates and different varieties of one crop yield differently. Until these factors have been defined precisely, it would be vain to forecast what may be done to alter them. Information about them, rich in scientific interest and practical implications, is sought in many ways, by detailed measurements of the physical conditions in crops, by growth studies on different crops and different varieties, and by studying the action of substances that affect leaf area. There is no simple approach to problems of this complexity, but when our greatly delayed constant-environment rooms at last come into use work will at least be simplified to the extent that effects of changing one factor in the environment can be studied while others remain constant.

My starting theme was " the range and aim of research ", and I am conscious that I have not done it justice. The aim, at least, I hope I have defined; also that I have shown that the complexity of agricultural research demands workers with inquiring minds and a wide range of skills and experience. Diverse as are the various subjects I have touched on, I have wholly failed to give the full range of our activities, but my failure can be rectified by reading the departmental reports. These are already summaries, and I do not intend to summarise them again. From what I have written it will be obvious that they record much about fertiliser use and the control of pests and diseases in a range of crops, but it will be less obvious that they also contain information on subjects as varied as the viability of insects flying at 5,000 feet; the activities underground of organisms as diverse as slugs, earthworms, fungi, nitrogen-fixing bacteria and a previously undescribed eelworm that transmits a soil-borne virus, thus adding a new danger to the already formidable list carried by those that are direct pests; the internal structure of viruses and the relative infectivity of intact virus particles and

their separated nucleic acids; the activities of enzymes in insects, bacteria and leaves; the biology of weeds and the use of pre-emergence weed killers; the effect of nutrition of bees on the incidence of their diseases and the best time to introduce pollinating bees into crops; the fungi in mouldy hay that cause " farmer's lung " and mycoses in cattle; the synthesis of clays; and another extension beyond our customary range, there is information on the incidence of diseases in dairy cows and the factors that affect the " S.N.F. content " of milk.

PHYSICS DEPARTMENT

H. L. Penman

Professor F. A. Brooks, from the University of California, spent six months with us as holder of a Guggenheim Fellowship. In September Mr. D. Rijks, newly appointed by the Empire Cotton Growing Corporation, started a six-month training in techniques for micro-meteorology before joining the research team in Namulonge, Uganda. Among many other visitors, Dr. J. F. Bierhuizen of Wageningen spent a period here for an exchange of ideas and experience on the physical aspects of transpiration and assimilation. J. L. Monteith was in Israel for three months, to advise the Government on research on crop evaporation. His mission was arranged and financed by the United Nations Bureau of Technical Assistance Operations, in co-operation with the World Meteorological Organisation. In January H. L. Penman attended a meeting of a European working party on irrigation, held in Wageningen by the Food and Agriculture Organisation.

Soil Physics

Electrical charges on clays

The delayed delivery of a new and more accurate conductivity bridge, and technical trouble in getting it working at its best, restricted work. Now, however, the new technique for estimating the nature of the electrical charge is doing all that was hoped for. Observations on illite were made, and others on montmorillonite are being organised, but the kaolins, about which so much information has been gathered in the past few years, were mainly studied. Past techniques were somewhat subjective in measuring changes in pH and observing electro-osmotic behaviour, as the clay was treated with successively increasing amounts of cetyl trimethyl ammonium bromide (CTAB). After the standard pre-treatment, the electrical state of the kaolin is that the planar charge is partly balanced by potassium ions, and partly by complex aluminium ions, the latter being relatively immobile. These cations are replaced by CTA^+ in two phases, during which the electrical conductivity changes in characteristic ways, the more mobile K^+ ions being replaced first. The new equipment gives more detail in these conductivity curves, some of which arises from the properties of the clay and some from the properties of the CTAB. Though the latter are important—the curves may help to show how other organic molecules are attached to clay—the main interest is in the behaviour of the clay. There is not always a sharp division between the phases (as suggested by the cruder results a year ago), but there is an overlap, at present interpreted by assuming that some of the K^+ ions are trapped in the aggregates, and are released only after the Al^{3+} ions start to be replaced. If there is no aggregation the phases *are* distinct. Whether this is relevant to the release of potassium and aluminium in field soil aggregates is not known. (Cashen.)

Soil structure

There was no test cropping on the field plots this year, but laboratory measurements (pore-space, permeability, gaseous diffusion) were made on soil crumbs from plots sampled to 6 inches. Some plots are on the site of the structure experiment, where, after 50 years of arable cultivation, they have been under fallow, ryegrass or cocksfoot for 4 years. The others are on Barnfield (continuously arable for over 80 years) and Highfield (permanent pasture). The grass seems to build up a more open (and more desirable) structure fairly rapidly, but stability in the structure increases more slowly. (Currie.)

Soil aeration

Accounts of the first stages in the basic work are ready for publication (see below 1.1, 1.2, p. 240). Part I, summarised last year, describes the technique and the check on its precision that leads to a new value of the coefficient of diffusion (D_0) of hydrogen in free air. Part II is based on a very detailed laboratory study of diffusion through dry, porous solids of varied particle shape. In the range of pore-space $0 < \varepsilon < 0{\cdot}8$ the general results satisfy $D = 0{\cdot}6\varepsilon D_0$, where D is the apparent coefficient of diffusion through the porous system, but this simple equation conceals interesting and important detail. For any material there is a small range of possible packing density, and within this range an equation of the form $D/D_0 = \gamma\varepsilon^{\mu}$ can be fitted, where γ lies between 0·8 and 1·0, and μ approaches the value of the index given by Bruggemann for the analogous electrical properties of two-phase media. Bruggemann's index is a shape factor for the *particle*; though what we need is a shape factor for the *pore*, two attempts were made to measure particle-shape factors. Measurements of surface area, and of settling velocity in a liquid, show only the expected general relationship with the values of μ, too imprecise to be of any quantitative use. Specification of a pore shape may prove easier for wetted materials. In the meantime a helpful generalisation is possible, for, using a simple model, it can be shown that for any porous system $D/D_0 = (l/l_e)^2 \cdot f \cdot \varepsilon$, where l_e/l is the tortuosity of the diffusion path, and f is a factor expressing the non-uniformity of cross-section of the path. This equation will probably be used for interpreting results being obtained from soils and other wetted materials. (Currie.)

Soil water

The rate of water used by growing plants can be estimated reasonably when soil water supply is not limiting, but it is not easy to specify what soil factors determine when water supply becomes "limiting". A new study of water movement in unsaturated soils began, to try to distinguish between transfer as liquid and transfer as vapour, and though the latter is expected to be more important when there is a temperature gradient, the first work was done at constant temperature. As a further technical simplification, not affecting the basic physics of the processes, the first working materials are consolidated, being small blocks of building stone. Much is already known about the pore-size distributions

in these blocks because they were used here in other suction studies. A technique was devised, tested and is apparently working well. A sealed diffusion cell contains the sample held between two saturated pads ("source" and "sink"), from which it is separated by fixed air gaps. The suction gradient imposed is regulated by saturating the pads with sodium chloride solutions at concentrations chosen to match the suction in the sample, in such a way that equal fluxes of water vapour distil from the source to the upper surface of the sample, and from the lower surface of the sample to the sink, i.e., transmission through the sample takes place at constant moisture content. As a check on performance, experiments without a sample gave a value of the coefficient of diffusion of water vapour in air as $D_0 = 0{\cdot}263$ cm.^{2} sec.$^{-1}$ at 25° C. Standard values range from 0·256 to 0·275 cm.^{2} sec.$^{-1}$, corrected to 25° C.

First results with two materials having very different pore-size distributions indicate that the liquid and vapour transfer interact, so that the total conductivity falls rather slowly from its value at complete saturation until the water content of the sample is so small that liquid continuity (it is presumed) no longer exists. Then the conductivity decreases very rapidly with decreasing water content, tending to a limiting value (D) for pure vapour diffusion, for which D/D_0 agrees with the value expected from the work of Currie. (Rose.)

The neutron-scattering technique for estimating water content in the field was tested thoroughly during the dry summer, with very disappointing results. Though much of the failure to achieve any close correlation between meter reading and measured soil-water content probably came from unavoidable variation in soil sampling, there are other causes attributable to the meter itself. It is hoped to eliminate these by converting the instrument from a rate meter to a scaling meter. (Long.)

Agricultural Meteorology

Because 1959 will long be remembered as a drought year it may be useful to give a summary table (Table 1) of the weather in which

Table 1

Weather Summary—Rothamsted 1959

Month	Mean Air Temp. (° F.)	Dew-point Temp. (° F.)	Soil Temp. at 1 foot (° F.) *	Wind Speed (m.p.h.) †	Rain (inches) ‡	Evapora-tion (inches) §	Sunshine (hours)	Solar radiation cal. cm.$^{-2}$ day^{-1}
Jan. ...	34 (37)	30	36	4·6	3·3 (2·5)	0·1	79 (52)	60 (54)
Feb. ...	38 (38)	35	37	5·6	0·1 (1·9)	0·2	62 (69)	82 (98)
Mar. ...	44 (41)	41	43	4·9	2·6 (1·9)	1·1	89 (118)	158 (202)
Apr. ...	49 (46)	43	48	5·1	2·5 (1·9)	2·0	135 (157)	279 (261)
May ...	54 (52)	46	54	4·9	1·3 (2·2)	3·7	219 (196)	403 (353)
June ...	59 (57)	50	59	4·1	1·2 (2·2)	4·0	233 (202)	445 (405)
July ...	63 (61)	55	64	4·1	4·5 ‖ (2·5)	4·6	277 (194)	455 (361)
Aug. ...	63 (60)	56	64	3·5	1·6 (2·6)	4·0	229 (183)	366 (306)
Sept. ...	59 (56)	52	60	3·5	0·2 (2·4)	3·0	208 (145)	282 (228)
Oct. ...	54 (49)	48	54	4·2	2·4 (3·0)	1·9	150 (104)	158 (129)
Nov. ...	43 (42)	41	45	3·4	2·4 (2·8)	0·4	65 (62)	68 (64)
Dec. ...	41 (39)	39	42	6·2	4·7 (2·6)	0·2	31 (45)	29 (40)
Total or mean	50·0 (48·2)	44·7	50·5	4·3	26·7 (28·5)	25·2	1,777 (1,525)	232 (208)

* Under grass.
† At 2 metres.
‡ $\frac{1}{100}$-acre gauge.
§ Open water: M.O. 6-foot × 6-foot tank.
‖ 2·3 inches on 10 July.

research and farming operations were done. (Some long-period averages are given in brackets.) The only two features to which special attention is directed are the high values of summer solar radiation (both in duration and intensity), and the high rainfall in July, which statistically brought us back to average for the first seven months of the year, and agriculturally saved many farm crops.

The micro-meteorological work in Great Field II was impaired in two ways. Half of the field was sown in May with a timothy/fescue mixture, but germination and growth were retarded during subsequent dry weather, and it was the beginning of August before a complete ground cover was established. Meantime the severe storm of 10 July flooded the field balance and lessened its efficiency.

On the other half of Great Field kale was grown, and simultaneous measurements were made over the kale and the grass.

Before outlining the 1959 work it is convenient to complete the history of earlier work.

Micro-meteorology

A long paper on the micro-meteorology of spring wheat is summarised below (1.8). A few general comments are made here, primarily to link this work with that of Monteith on radiation and on assimilation. The part of the survey dealing with transpiration shows how the flux of water vapour above the crop is built up within the crop. The flux of carbon dioxide for photosynthesis, physically similar but in the opposite direction, may be governed by a rather more complicated plant response to the intensity and distribution of light. All the green leaves of the wheat plant probably contribute equally to the transpiration stream: some day it may be possible to state how they contribute to assimilation and respiration.

The ventilation part of the survey reveals that air movement in the crop does not vary greatly with external wind speed, because the upper leaves bend over in stronger winds, tending to form a " self-seal " at the top of the crop; insects that prefer calm conditions for flight will usually find them inside a wheat crop. Conditions for dew formation were examined, and precise estimates can be given of when dew formed and how long it persisted. Though dew forms on wheat as drops, each covers perhaps 30 stomata and so is big enough to provide fungus spores with room enough to germinate and infect.

Professor Brooks studied some of the topics that were only briefly mentioned in the survey. E.g., an adventitious temperature ripple—of no British agricultural significance—has a parallel in Californian orchards at the time when the frost hazard is greatest. Professor Brooks left us with four possible explanations of the phenomenon, broadening our ideas in the process. (Penman and Long.)

So far there has been little opportunity to analyse the 1958 results with sugar beet, and none at all for the 1959 data for grass. Observations made in 1959 were similar to those in 1958, but a more sensitive system for measuring temperature differences was introduced. This will be fully exploited when aspiration of the wet- and dry-bulb thermometers is achieved, and it is hoped that in the

summer of 1960 reliable wet-bulb depressions, correct to 0·02° C. or better, will be continuously recorded.

Recording in and over the test site began immediately after drilling of the grass seed and continued into mid-winter. Later in the season, detailed enough observations over kale were taken to compare estimated transpiration rates, for which the aerodynamic formula will be used. (Long.)

Heat and water balance

The grass cover on the field balance was not complete until August. Average transpiration during that month was 3·35 mm./day, a few per cent more than the evaporation from the nearby 6 feet square open water tank. In previous years transpiration from wheat and sugar beet never exceeded tank evaporation by more than 24 per cent over a month, so the balance records show that differences in the water consumption of crops having different heights and structures are small. The grass was cut at the end of August, and in September (nearly rainless) there was no obvious growth, and transpiration was only 32 per cent of tank evaporation.

During the growing season, net radiation was recorded over both grass and kale, and in these and other crops on the farm the profiles of short-wave radiation (solarimeter) and of visible light (photocell) were occasionally measured. There are important differences in the amount of light that gets through crop canopies. A mature stand of kale intercepted 99% of radiation incident at the top of the crop; a potato crop intercepted 95%; spring wheat, 100 cm. high in July, intercepted only 70%. This failure to absorb completely, a consequence of leaf arrangement, may be one factor that reduces the net assimilation rate of cereals below that of other crops.

Analysis of net radiation records for the past 3 years shows that the amount received by crops during daylight hours is a constant fraction of the incoming short-wave radiation throughout much of the growing season, the constant varying little with crop species. There is here the possibility of a useful short cut to estimating the net radiation term in the expression for potential transpiration, i.e., it may simplify our computations of irrigation need.

Radiometry

In its final form (1.4) the small portable solarimeter can be made quickly and cheaply; models worked without trouble at Rothamsted throughout the year, were used successfully in Israel and are being tried in East Africa. A combination of two units, with a suitable potentiometer circuit, accurately and rapidly estimates the reflexion coefficient of any surface over which it is exposed (1.5). (Monteith and Szeicz.)

Another instrument in the trial stage is a net radiometer not needing forced ventilation. Progress was good, and there is now a prospect of getting accurate weekly totals of both net radiation and short-wave radiation from equipment costing less than £40 altogether.

Study of the performance of the commercial Gunn–Bellani radiation integrator was completed (1.6). The existence of a tem-

perature-dependent threshold of response probably results from incomplete evacuation of air during manufacture. (Monteith and Szeicz.)

Carbon dioxide flux

The meteorological aspects of the carbon dioxide flux over a crop of sugar beet were published (1.7). During August and September the calculated value of net assimilation was 3·8 mg. cm.$^{-2}$ day^{-1}, based on measured gradients, and other weather parameters: the " observed " value was 5·2 mg. cm.$^{-2}$ day^{-1}, based on plant sampling and estimation of dry matter increase by the Botany Department. During October and November, the atmosphere apparently ceased to be important as a source of carbon dioxide, large quantities then coming from the soil, much more than the crop could take up.

A correlation of calculated rate of photosynthesis and weather is being attempted. For short-wave radiation intensities below 0·4 cal. cm.$^{-2}$ min.$^{-1}$ the assimilation rate of sugar beet is proportional to light intensity: above, there is evidence of light saturation. Wind speed is important too, for assimilation rates decrease when atmospheric turbulence does not maintain the normal concentration of carbon dioxide above the crop: on one calm, sunny day it was decreased to 220 p.p.m. (normal $\simeq$ 300 p.p.m.).

Carbon dioxide gradients over the kale were measured, but no worthwhile records were obtained over the grass because of technical trouble with the gas analyser. Late in the season the carbon dioxide flux from the soil was measured to compare with the high values observed during the sugar-beet study in 1958. (Monteith and Szeicz.)

Irrigation at Woburn

Though the mid-July storm at Woburn was less severe than at Rothamsted, there was heavy rain then and early in August, so that Woburn had not quite the intensity of drought experienced elsewhere in the country. Nevertheless, it was the kind of summer in which benefit from irrigation was a foregone conclusion, and the crop responses ranged from 50 to 150 per cent increase with full irrigation (C treatment in Table 2). For the first time in 9 years irrigation continued into September. The table should be read with the following notes. *Grass:* After five years the quality of the stand in spring 1959 was rather poor, with much *Poa annua*. It was decided to leave it for one more season, and the plots were ploughed up in September 1959 after watering the non-irrigated plots to make ploughing possible. As a result of the poor initial stand, and the shorter season, the best yields are less than some previously obtained. *Sugar beet:* On occasions during hot, dry periods plants wilted on all plots, even while the top-soil of the irrigated plots was visibly wet. Presumably assimilation was checked in these periods. *Spring wheat:* There was a little disease on the crop, irregularly distributed without any clear association with either fertiliser or watering treatment. Yields are as dry matter, i.e., smaller than the conventional figures, which include some water. *Spring beans:* The response to water was fantastic, the irrigated plants growing to

more than twice the height of the controls, so that they interfered with the spread of water, and the plants near the spray lines grew much taller than those more remote. Because of this variability the yields on the irrigated plots are not very precise. There was no

TABLE 2

Woburn Irrigation, 1959

Crop	Period	Rain (inches)	Irrigation (inches)	Plot	Yield (cwt./acre)	
Grass	27 Apr.–7 Sept.	5·5	—	ON_2	28	Dry matter 6 cuts
				ON_4	35	
		5·5	6·8	CN_2	57	
				CN_4	73	
Sugar beet	27 Apr.–28 Sept.	5·6	—	ON_1	62	Sugar
				ON_3	58	
		5·6	7·3	CN_1	88	
				CN_3	88	
Spring wheat	27 Apr.–20 July	3·3	—	ON_1	15	Grain
				ON_3	14	
		3·3	4·7	CN_1	24	
				CN_3	25	
Spring beans	27 Apr.–3 Aug.	4·7	—	O	9·4	Grain
				OS	7·7	
		4·7	4·5	C	21	
				CS	21	

response to dung, and the other variant (treatment S) in the table is a spray against black-fly: this seems to have depressed the yield on the unwatered plots. Again, yields are as dry matter. (Penman and Barnes.)

CHEMISTRY DEPARTMENT

G. W. Cooke

J. M. Bremner left in August to take a post at Iowa State University. I. K. Otter joined the staff temporarily in September. A. C. D. Newman returned from Russia, where he spent a year working at the University of Moscow under an exchange scheme organised by the Russian Ministry of Agriculture, the British Council and the Agricultural Research Council. B. P. Pleshkov returned to the Timiryazev Agricultural Academy, Moscow, in July. T. Z. Nowakowski was invited to attend a Conference on " Organic Manures and the use of Peat in Agriculture " at Szczecin in Poland, where he gave a paper on British work on organic manures. G. W. Cooke visited experimental stations and farms in France where research is being done on fertilisers, and on new kinds of cropping, at the invitation of Société Commerciale des Potasses d'Alsace. In October Cooke was invited by the Swedish Federation of Fertiliser and Lime Industries to visit Stockholm and read a paper on British work on fertilisers, soil fertility and crop production. He also took part in a Round Table Conference arranged by the Royal Swedish Academy of Agriculture and Forestry.

D. P. H. Tucker of the Colonial Research Service left in September to continue his training at Cambridge. R. G. Heathcote joined the Department for training in field experimentation and soil-fertility work. P. Arambarri (Spain), M. Birecki (Poland), S. N. Chakravarti (India), M. Kushizaki (Japan), M. Salomon (U.S.A.) and L. V. Vaidyanathan (India) all worked in the Department during the year.

J. M. Bremner was awarded the D.Sc. Degree of London University. S. N. Chakravarti was awarded the London Ph.D. Degree.

Organic Matter in Woburn Soils

E. M. Crowther (Russell, E. J. and Voelcker, J. A. (1936), *Fifty years of field experiments at the Woburn Experimental Station.* London: Longmans, pp. 315–345) discussed changes in organic carbon contents of the soils of the Continuous Wheat and Barley Experiments at Woburn. The results were difficult to interpret because of the systematic arrangement of the treatments and the presence of elementary carbon in some of the wheat plots. With continuous cereals grown with fertilisers, but no farmyard manure, the percentage of organic carbon in the soil fell from about 1·5% in 1876 (when the experiments started) to about 1·0% in 1927. Recent deeper ploughing may have increased the organic matter in layers of soil originally unploughed. The 1959 samples were therefore taken to several depths, so that analyses could be adjusted for comparison with earlier results when the land was ploughed less deeply. Organic matter has been lost at about the same rate, or a little faster, from 1927 to 1959 as between 1888 and 1927 on the plots

that had inorganic fertilisers in which sodium nitrate supplied the nitrogen. With ammonium sulphate instead of sodium nitrate, organic matter was lost more quickly in the recent period. Organic matter may have oxidised more rapidly on the ammonium sulphate plots because they have been fallowed more. On the nitrate plots the *annual* loss of organic carbon between 1888 and 1959 was about 0·009 per cent (of C), twice the rate with old organic residues on one of the plots (7–1) of heavier soil on the Hoosfield Permanent Barley Experiment at Rothamsted.

The soils of both sites at Woburn now contain very little organic carbon; the barley site is lower than the wheat, and the lowest values (0·56% C) are on the plots that received ammonium sulphate. Soil is now lost from these sites by water erosion, perhaps because the soil contains too little organic matter. Otherwise the agricultural significance of these low levels of organic matter is not known; nor is it known whether crop yields would be higher if the levels were higher. (d'Arifat and Warren.)

The Diffusion of Ions in Soil

Crops can only take up nutrients when root and nutrient ion are in contact. Mobile ions, such as nitrate, may meet roots by being washed downwards in water percolating through soil, otherwise contact can only occur as ions migrate by diffusion in films or pockets of water in or on soil particles. Although the processes by which ions move must affect the value of plant nutrients supplied by soils and by fertilisers, the factors that influence diffusion have rarely been studied systematically. Newman began work on ion-diffusion processes in soil and related materials while at Moscow University and continued it when he returned to Rothamsted.

An apparatus was developed from that used to determine diffusion coefficients of aqueous solutions, in which the porous medium is a diaphragm confined between two sintered glass disks. Ions from an aqueous solution on one side of the diaphragm diffuse through to a less concentrated solution on the other. At a steady state the amount of diffusing substance which passes through the diaphragm in a given time is determined chemically.

Sand was washed, ground and fractionated by sedimentation into the size ranges 10–20 μ and 20–50 μ and used as the porous medium. Two conductivity measurements were made, one with sand and electrolyte between the plates, and the second with electrolyte alone. The number of ions migrating by either conductivity or diffusion is proportional to the area available for migration and inversely proportional to the distance they travel. Hence the function (effective area/path length) describes the resistance of the media to migration; the ratio of the value of this function (determined from diffusion or from conductance measurements) to the value calculated from the physical dimensions of the compartment in which the diaphragm is confined is defined as the migration permeability (P). Some values of P already obtained show approximate agreement between the two independent methods for obtaining the migration permeability, and confirm that inert materials in particles of size 10 μ or greater interfere with migration only by

blocking the path of the ions. With smaller particles the diffuse double layer may interfere with this simple pattern, and techniques are being improved to test this. (Newman.)

Cation-exchange Capacities of Plant Roots

In continuing work on the cation-exchange capacities (CEC) of plant roots (*Rep. Rothamst. exp. Sta.* for 1958, p. 58), reasons were examined for the drift to acid pH values after suspensions of roots in salt solutions are neutralised in determining CEC. In collaboration with Holden (Biochemistry Department) the drift was shown to resemble that with minced leaf suspensions and caused by pectin-esterase breaking pectin into pectic acid and methanol. Neutralised root suspensions contained methanol and showed pectin-esterase activity. Pretreating the roots with boiling water, and with solvents of pectin, greatly decreased the CEC values of legume roots. The buffer curves of roots also indicated that pectin is important in exchange reactions.

No close relationships were found between CEC values and apparent dissociation constants calculated from pH values in *N*-KCl of roots previously saturated with H^+ by HCl treatment, or with the nitrogen contents of roots. In pot experiments with several crops, CEC values changed only slightly during the first two or three months of growth, but as the crops matured the CEC values for coarse and fine roots differed; for example, with kale the values for coarse and fine roots were respectively 26 and 67 m.eq./100 g. of dry matter, and smaller differences occurred with other crops. Variations of this kind partly invalidate the conception that each crop has a specific value for CEC of its roots, and show that a better basis than dry-matter weight is needed for expressing results. Work reported last year showed CEC values of 13–16 m.eq./100 g. dry matter for clover roots; other workers have reported 40 m.eq. The higher values have now been found for clover roots from cultures in flint and nutrient solutions, but the lower values, which are characteristic for cover grown out of doors in soil, were found when plants were grown in sand–vermiculite mixtures. It might be argued that values with clover from the field are low because the finer and more active roots are lost in sampling, but this cannot be so with plants grown in sand and vermiculite when all roots are extracted.

The present circumstantial evidence does not prove that CEC values are very important for understanding ion-adsorption processes. Some published results for uptake of mono- and divalent cations agree qualitatively with what might be expected if the Donnan theory of membrane equilibria governed ion adsorption. In the present investigation, when clover and perennial ryegrass grew under similar conditions, corresponding K/Ca ratios of plant tops were 0·31 and 2·1 for CEC values 48 and 22 m.eq./100 g. D.M. respectively. The correlation coefficient for $\frac{CEC_1}{CEC_2} \times \frac{K_2}{K_1}$ for 24 pairs of comparisons of various crops was +0·4654, which was just significant. (Heintze.)

Nitrogen in Soils

Mass spectrometer

A small mass spectrometer made by Vacuum Industrial Applications Ltd., Wishaw, Scotland, was installed in 1959, which will help our work on soil nitrogen and provide facilities for other departments that wish to use stable isotopes of light elements. A series of difficulties prevented it from becoming fully operational. Several minor and major technical faults in the apparatus as delivered have now been rectified, but delivery of components for the handling equipment for the gas admission part of the spectrometer was also delayed. The gas-line necessary for converting samples of ammonium salts to nitrogen gas is now almost complete. (Newman.)

Some experiments with ^{15}N were started on the fixation of atmospheric nitrogen in a poor soil by microbes that are not symbionts, to see how fixation is affected by oxygen, carbon dioxide, and by additions of plant material and nitrate. (Birecki, Jenkinson and Newman.)

Fixation of ammonia by soil organic matter

Recent work suggests that, when soils are fertilised with gaseous or liquid ammonia, more ammonia is fixed by the organic fraction than by the clay fraction, and an attempt was made to determine the ammonia fixed by the organic matter in mineral and organic soils. Various techniques, including saturating the soils with potassium and removing clay minerals with hydrofluoric acid before treating with ammonia, showed that much ammonia was fixed by soil organic matter in moist or air-dry soils, but there was no satisfactory way of measuring this fixation in soils containing ammonia-fixing clay minerals. The theory that fixation by soil organic matter and by lignin involves oxidation of phenolic hydroxyl groups at which ammonia is then fixed could not be substantiated. Fixation of ammonia by lignin and by organic soils occurs without oxygen, and the reaction of lignin with ammonia does not destroy phenolic hydroxyl or methoxyl groups, or the units responsible for forming aromatic aldehydes when lignin is oxidised with alkaline nitrobenzene. Very little, if any, of the ammonia-N fixed by lignin is in the form of free amino groups as determined by the Van Slyke nitrous acid method. (Bremner.)

Mineralisable-nitrogen in soils

The relationship between mineralisable nitrogen in soils, determined by laboratory incubations, with crop performance was examined in pot and field experiments. In the pot experiments (with Close) yields of dry ryegrass, and nitrogen uptakes, were significantly correlated with the mineral-N in freshly sampled soils, and with the mineral-N released by incubating soils that had been air-dried and re-wetted; there was no significant correlation with the mineral-N released on incubating the fresh soils. With 22 soils used for field experiments on barley, yields of barley grown without nitrogen fertiliser were correlated with the amounts of mineral-N in fresh soils, and also with the amounts released by incubating soils that had been air-dried. Soils from 14 potato experiments

showed no significant correlations between unfertilised yields and laboratory measurements of " available " nitrogen.

Both the mineral-N contents, and also the amounts of mineralisable-N released on subsequently incubating air-dried soils, increased during storage, were less when the soils were stored in sealed polythene bags than when in paper bags; the increases were much smaller when air-dry soils were stored at −10°. (Gasser.)

Movement of fertiliser nitrogen dressings in soil and uptake by wheat

100 lb. of fertiliser N per acre were applied as calcium nitrate or as ammonium sulphate, either in the autumn or in the spring for winter and for spring wheat crops on light soil at Woburn; adjacent plots of uncropped soil were also dressed. Nitrogen applied in autumn was leached from the surface soil; by December just over half of the total quantity remained in the top 36 inches, but by March only 10% of the nitrate dressing and 20% of an ammonium sulphate dressing remained in the top 36 inches of soil, and most of this was in the 18–36-inch layer. In contrast, the whole of the dressing of either form of nitrogen applied in spring to bare land was in the sampled depth, and most was in the upper 18 inches, until the final sampling in August. Both winter and spring wheat removed almost all of the fertiliser nitrogen by the end of May, and at harvest even the soils given fertiliser contained very little mineral-N. Little of the fertiliser-N applied in autumn was recovered by winter wheat and none by spring wheat. Similar amounts of fertiliser-N applied in the spring as ammonium sulphate or calcium nitrate were recovered by winter and spring wheat, but whereas more of the total nitrogen recovered was in the grain of winter wheat at harvest with ammonium than with nitrate, the reverse was true with spring wheat. The uptake of fertiliser-N by the wheat was maximal at the end of May; at harvest winter wheat contained 8% and spring wheat 32% less nitrogen than this maximum. (Gasser.)

Soil Phosphate

Phosphate equilibria in calcareous soils

In previous work the total isotopically exchangeable phosphate (P_e) was divided into fractions exchanging at different rates which were affected by external factors in different ways (*Rep. Rothamst. exp. Sta.* for 1957, p. 62; for 1958, p. 49). The total surface phosphate (P_s) (given by P_e–P_{ss}, P_{ss} being phosphate in the soil solution) in 40 calcareous soils from England and Spain was divided into " rapid " and " slow " exchanging fractions (the half-times of exchange were 3·70 hours and 32·9 hours respectively). The " rapid " and " slow " exchanging phosphate values, expressed as ratios of the total surface phosphate, were positively related to both the clay and the $CaCO_3$ contents of the soils. (Arambarri.)

" Lime potential " and " phosphate potential " values (*Rep. Rothamsted. exp. Sta.* for 1949, p. 29) were calculated from concentrations of calcium, phosphate and hydrogen ions in the soil solutions for 53 calcareous soils from England and Spain whose total phosphate (P_t) and P_e values were between 21–533 mg. and 1·9–

24·8 mg. P/100 g. soil respectively. The lime potential values were in the range 6·43–6·85, and variation from the theoretical value of 6·60 at the partial pressure of CO_2 in air (0·0003 atmos.) was presumably related to the nature of the calcium carbonate surfaces. The monocalcium phosphate potential ranged from 7·23 to 8·59, suggesting the presence of calcium phosphates similar to, and slightly more basic than, octocalcium phosphate.

The influence of $CaCO_3$ content on phosphate equilibria was examined in groups of soils obtained from pairs of adjacent sites where $CaCO_3$ and the other mineral constituents were thought to be of similar origins. There was a linear relationship between $\frac{P_{slow}}{P_{surface}}$ and $CaCO_3$ content for two groups of soils with more than 8% of $CaCO_3$. Isotopic exchange experiments using ^{45}Ca on a few of the soils from different sites showed that the specific surface of their $CaCO_3$ varied between 6·4 and 23·8 M^2/g. (of $CaCO_3$). The ultimate crystallites of the soil $CaCO_3$ must be very small, because the specific surface of calcite is about 0·151 M^2/g. for crystals of average diameter 25 μ (*Rep. Rothamst. exp. Sta.* for 1958, p. 50). With soils of similar $CaCO_3$ and total P contents, high specific surfaces of $CaCO_3$ are related to high values for the ratio: $\frac{P_{slow}}{P_{surface}}$.

10 mg. of P were added (as monocalcium phosphate) to these soils and recoveries were measured after incubating for 1, 2 and 6 months at constant temperature and field moisture capacity. The values of the ratios $\frac{P_{rapid}}{P_{surface}}$ and $\frac{P_e}{P_t}$ were nearly at equilibrium after incubating for between 2 and 6 months, and were significantly greater than the values obtained for the untreated soils. Lower recoveries were obtained with soils containing much $CaCO_3$ of high specific surface. The total isotopically exchangeable phosphate (P_e) was linearly related to the equilibrium phosphate concentration in 0·02*M*-KCl; both values decreased with time, and the fall was proportionately more for the phosphate concentrations than for the total labile phosphate. (Arambarri and Talibudeen.)

Phospate equilibria in acid soils and phosphated clay minerals

In extending work reported earlier (*Rep. Rothamst. exp. Sta.* for 1958, p. 49) clay minerals were treated with $5.10^{-5}M$ phosphate for times up to 9 months. Kaolinites retained twice as much phosphate as did montmorillonite and glauconite, reflecting their lower negative surface charge density and higher edge : sheet area ratio. The net proton uptake by the clays was approximately proportional to the equilibrium pH and was much larger than the phosphate uptake, presumably because of the relatively high chloride concentration used. In a subsidiary experiment "Merck" kaolinite in equilibrium with 0·02*M*-KCl at pH 3 was treated with potassium phosphate at pH 3 in concentrations varying from 5.10^{-1} to $5.10^{-5}M$ for times buffers up to 4½ months. The calculated net proton uptake per g. of clay was several times greater in $5.10^{-1}M$ and $5.10^{-2}M$ treatments than in the other treatments, indicating that more of the clay mineral was broken down. Phosphate uptake was greater at the higher

concentrations and was linearly related to the net proton uptake per g. of clay after $4\frac{1}{2}$ months.

A comparison of soil suspensions and the clays that had been treated with $10^{-5}M$ phosphate showed that phosphated montmorillonite had ion-activity products for (Fe^{3+} or Al^{3+}) $(OH)_2.H_2PO_4$ similar to those obtained with 28 British soils; 26 Indian soils gave values less than those with montmorillonite and approaching the ion-activity products of phosphated kaolinite and glauconite. Kaolinite treated with stronger phosphate solutions formed insoluble phosphates that were more acidic than variscite or strengite and resembled the precipitated synthetic phosphates containing Fe or Al in amounts equivalent to the phosphate. (Chakravarti and Talibudeen.)

Rates of growth and phosphorus uptake by ryegrass on calcareous soils

Calcareous soils from Rothamsted with a lime potential (pH $-0{\cdot}5$ pCa) of 6·4 and with less than 15 mg. (P) of isotopically exchangeable phosphate per 100 g. of soil show an approximately linear relationship between the phosphate concentration in equilibrium with $0{\cdot}01M$-$CaCl_2$ and total isotopically exchangeable phosphate. In glasshouse experiments with ryegrass in Rothamsted soils, yield increases and phosphorus uptakes were closely correlated with either of these measurements, although one is a measure of intensity and the other is a quantity.

A pot experiment with three groups of soils (pH $-0{\cdot}5$ pCa = 5·9–6·4) derived from different calcareous parent materials was done to see whether phosphate concentration, or total isotopically exchangeable phosphate, governed the growth of ryegrass when N, K and micronutrients were optimal. The soils in each group had approximately the same total exchangeable phosphate, and between groups the phosphate concentration differed by a factor of two or three. Table 1, which gives the yields of grass on five of the soils at the first four harvests, shows that the first yields, after 41 days, were closely correlated with phosphate concentrations and were almost independent of the total isotopically exchangeable phosphate. First yields from soils 1, 2 and 3 were almost identical, although soil 3 had twice as much exchangeable phosphate as soil 1. At later harvests, the fourth 113 days after sowing is a good

TABLE 1

Yields of ryegrass, phosphate concentration and total isotopically exchangeable phosphate for 5 calcareous soils in a pot experiment

Parent material of soil	pH-0·5pCa	Isotopically exchangeable phosphate (mg. P/100 g.)	P concentration (micromoles P/litre)	Yield (g. dry matter/pot) 41 days	64 days	90 days	113 days
1. Silurian limestone ...	6·46	6·5	0·7	0·53	0·42	0·48	0·26
2. Oolitic limestone ...	6·39	9·3	0·8	0·52	0·72	0·84	0·59
3. Oolitic limestone ...	6·21	13·7	0·7	0·58	0·81	1·02	0·92
4. Clay-with-flints ...	6·35	13·9	1·4	0·89	0·91	1·13	1·01
5. Keuper marl ...	5·93	13·7	1·7	1·48	0·96	1·25	0·99

example, yields of grass were not related to phosphate concentration, but were proportional to isotopically exchangeable phosphate. This work confirms that described earlier (*Rep. Rothamst. exp. Sta.*

for 1957, p. 59). On both calcareous and acid soils the initial rate of growth of ryegrass depends mainly on phosphate concentration in the soil, but total yield is approximately proportional to total isotopically exchangeable phosphate. (Mattingly, Kuskizaki and Close.)

Measuring " available " phosphorus

Earlier work (R. G. Warren. *Proc. Fertil. Soc.* no. 37) on the Exhaustion Land and Four-course Rotation Experiments suggested that sodium bicarbonate is a more reliable extractant than acids for estimating the P status of slightly calcareous soils. The soils of the old Rotation Experiment on Agdell were used to extend the work and to estimate more precisely the level of soil P below which superphosphate increases the yield of barley. The critical level in extracting with bicarbonate is 1 mg. P/100 g. soil, agreeing closely with Mattingly's value of 0·9 mg. P obtained in pot experiments with ryegrass. Potatoes respond to superphosphate when soil P is greater than this. The critical level was not determined because potatoes responded to superphosphate on all the soils used. Field experiments on soils with higher levels of P are needed, and some plots of the Barnfield Continuous Mangold Experiment will be used. These differences between the behaviour of potatoes and barley are important when interpreting soil analyses for farmers; they may depend on differences in physiological processes within the crops or in the nature and extent of their root systems.

A tentative conclusion is that extractants with pH values above 4 are more satisfactory than those below. Different methods of soil analysis are compared most simply on old arable soils, where biological changes affect nutrient supplies much less than on soils where green crops, old grassland or bulky organic manures have been ploughed in. In these last conditions mineralisable organic phosphorus may be important. (Johnston and Warren.)

Potassium in Soils

In pot experiments seventy-six soils from a wide range of soil types are being continuously cropped. The potassium reserves of many were soon exhausted, but some have continued to supply ryegrass satisfactorily for 18 months. The amounts of non-exchangeable potassium released in this period have varied from nothing to more than 2,000 lb. K/acre. (Arnold and Close.)

Relation of potassium supply to size of clay

A group of eighteen arable soils which had not received heavy dressings of potassium fertilisers were used in laboratory work to investigate the value of potassium held by soils. Measurements of " fine " clay ($< 0{\cdot}1\ \mu$), and its potassium content, separated the soils into three groups which fitted the following rates at which non-exchangeable K was released in the pot experiment:

Rate of release	Equivalent amount (lb. K/acre)
Low	<200
Medium	200–1000
High	>1000

One exceptional soil released K from particles of silt size; with all other soils releases of K were correlated with amounts of fine clay and with K levels in the fine clay. Measurements of 0·1–0·3 μ clay fractions were nearly as useful as those of fine clay for grouping the soils according to their power of releasing non-exchangeable K to grass, but measurements of 0·3–2 μ fractions were poorly correlated with this power. Chemical extraction of mechanically separated fractions from a range of soils containing more than 1% of total K, showed that from half to three-quarters of the K occurs in particles too large to contribute significantly to the K provided by the soil. (Arnold.)

Relation of potassium supply to clay minerals

Little success has yet been achieved in relating the potassium supply from soils to crops with the clay minerals present, but the behaviour of the minerals most important in soil–potassium relationships (principally micas and hydrous micas) has been too little studied. X-ray-diffraction data for < 2 μ clay separates are of only limited use for assessing what amounts of K soils of different origins will supply to crops, probably because the micas and hydrous micas in the " coarse " clay of this fraction, although they dominate the X-ray spectrograms, contribute little potassium to crops.

The potassium distribution in mechanical separates of soils from the long-continued Rotation I Experiment at Saxmundham was determined before and after continuous cropping with ryegrass for 18 months in the glasshouse. The non-exchangeable K released from the soil which had received K fertiliser annually for 60 years and the unfertilised soil were respectively 60 and 16 mg. K/100 g. Cropping in the greenhouse lowered the K content of the mechanical separates of the K-fertilised soil to the level in the unfertilised soil. More than two-thirds of the potassium released came from the $< 0{\cdot}3$ μ fraction in both soils. The internal surface areas of the clay fractions (< 2 μ) of the K-treated and untreated soils at Saxmundham (measured by R. Greene Kelly) were respectively 260 and 290 m.²/g. These values may differ because the micas and hydrous micas of the untreated soil were depleted of potassium.

The amounts of potassium removed by crops from the Saxmundham soils over 60 years were estimated by Cooke *et al.* (*J. Soil Sci.* (1958), **9**, 298); they suggest that from one-half to two-thirds of the " native " K removed must have come from the subsoil. Subsoils are usually less weathered than top-soils, and they may often be important in supplying non-exchangeable potassium to deeply rooting crops. (Arnold.)

Potassium fixation

In measuring added potassium that has been fixed in soils of some long-term experiments at Rothamsted, sulphuric and hydrofluoric acids were used instead of nitric acid to " strip " the soils progressively. A simplified method is being developed to determine what part of the " fixed " fertiliser K acts as a reserve to maintain the exchangeable K level in Rothamsted soil. This K value may supplement, or even substitute for the exchangeable K value, es-

pecially with soils that have been sampled immediately after an exhausting crop has been grown, and before equilibrium between exchangeable K and fixed K has been re-established. (Johnston and Warren.)

Field Experiments on N, P and K Fertilisers

Nitrogen for winter wheat

In four field experiments with winter wheat, nitrogen top-dressings in late February caused more lodging than the same amount of nitrogen given either when sowing in October or at the end of April. Nitrogen in April increased yields more than February dressings, which, in turn, were a little more effective than October dressings. The experiments were on heavy soils; only on such land is nitrogen applied in autumn effective, for similar experiments on light land at Woburn showed no response to autumn dressings. (Widdowson and Penny.)

Nitrogen for barley

Six field experiments testing ammonium sulphate on barley showed that combine-drilling was superior to broadcasting on the seedbed at four of the six centres when 0·3 or 0·6 cwt. N/acre was given, but with 0·9 cwt. N broadcasting was better. From fifteen experiments of this kind with barley done in the last 3 years, the average gains from combine-drilling over seedbed broadcasting were:

Rate of N fertiliser	Extra yield of grain from combine-drilling (cwt./acre)
Low...	0·9
Medium	0·8
High	−0·4

The experiments also tested divided dressings. When the medium rate was applied half by combine-drill and half as a late-spring top-dressing, splitting the dressing gave higher yields than drilling at fourteen of the fifteen centres, and the average gain was 1·2 cwt./acre of grain. In 1957 and 1959, but not in 1958, dividing the heavy dressing gave higher average yields than applying all by combine-drill. Combine-drilling the highest rate of nitrogen may have led to the fertiliser injuring germination, and attempts are being made to develop a coulter that separates seed and fertiliser.

In other experiments with barley, 0·5 cwt. K_2O/acre increased yields significantly at two of five centres; twice as much potassium was not worthwhile at any centre. Large increases in yield resulted from 0·3 cwt. N/acre at four centres; 0·6 cwt. further increased yields at only two. The nitrogen response was affected by potassium fertiliser at only one centre. The two years' work shows that 0·5 cwt. K_2O/acre generally suffices for cereals, even on soils with little " available " potassium, and that nitrogen fertilisers give a full return with this level of potassium manuring. (Widdowson and Penny.)

Urea for barley

Urea and ammonium sulphate were compared in four experiments on barley by combine-drilling the fertilisers at rates supplying

0·25, 0·5 and 0·75 cwt. N/acre. The highest rate greatly checked germination and decreased plant establishment, and the medium rate checked growth, though less. Although the heaviest rate of ammonium sulphate slightly checked growth, it gave consistently more grain than urea. Differences between ammonium sulphate and urea were less at two centres drilled in February and greater at the other two drilled in March, in which urea gave significantly less grain than ammonium sulphate at each level of manuring. (Widdowson and Penny.)

Nitrogen for grass

A stand of Italian ryegrass on heavy clay-loam at Rothamsted was used to compare top-dressings of nitrogen applied on 4 November, 4 February or 11 March. When cut on 11 April autumn dressings gave the highest yields; calcium nitrate and ammonium sulphate behaved similarly. This work on grass, like that on winter wheat (described above), shows that nitrogen applied in autumn is not easily leached out from the upper layers of heavy soils, and autumn applications may sometimes be better than spring dressings.

Tests of nitrogen and potassium fertilisers on pure stands of grass in the experiments begun in 1958 (*Rep. Rothamst. exp. Sta.* for 1958, pp. 46–47) were continued in 1959. Fresh dressings of urea–formaldehyde fertiliser were less effective at each cutting than half the equivalent amount of nitrogen applied as " Nitro-Chalk ". The residual effects in 1959 of urea–formaldehyde dressings given in 1958 were no greater than the residual effects of equivalent " Nitro-Chalk " applied in 1958. The experiment begun in 1958 to test different levels of nitrogen and potassium fertilisers on Italian ryegrass showed large gains from nitrogen over the season. Potassium had little effect on yields of the first cut, but increased the second and third cutting slightly. (Widdowson and Penny.)

Effects of fertilisers on forms of nitrogen in grass

Work started in 1958 to examine how fertilisers affect the forms in which nitrogen accumulates in grass was extended in 1959. Italian ryegrass grown on clay-loam soil at Rothamsted contained much more nitrate with sodium nitrate applied before sowing than with ammonium sulphate. Early in the season plots given 1·0 cwt. N/acre produced dry grass containing 0·64% NO_3-N with nitrate and 0·28% NO_3-N with ammonium sulphate. It is worth noting that some people consider that 0·2% of NO_3-N may be dangerous to stock. Grass given ammonium sulphate contained more NH_4-N, amide-N and α-amino-N than when given nitrate. These experiments are being repeated on Italian ryegrass grown on light soil at Woburn. At the first cutting ammonium sulphate, ammonium nitrate, sodium nitrate, calcium nitrate, magnesium nitrate and urea all supplying the same amount of nitrogen gave similar yields. The dressings were repeated for a second cut, but drought stopped growth; the check from drought was accentuated by nitrogen fertiliser, and where heavy dressings had been given, some of the plants died; nitrate caused most damage. (Nowakowski.)

Residual Effects of Phosphate Fertilisers

Acid soils

An experiment started in 1954 to measure the residual values of superphosphate and Gafsa rock phosphate on an acid soil was completed in 1958; results have been reported for the first three years (*Rep. Rothamst. exp. Sta.* for 1955, p. 46; for 1956, p. 48). Table 2 shows grain yields in 1957 and 1958 when barley was grown with adequate nitrogen and potassium fertiliser but with no further phosphate.

Table 2

Residual effects of phosphate fertilisers on barley in 1957 and 1958

		Yields of grain (cwt. dry matter/acre) 1957	1958
Without P fertiliser		29·4	21·8
Increases due to residues from 3·0 cwt. P_2O_5*/acre applied as:*			
Superphosphate	1954	+5·9 **	+6·5 **
	1955	+6·0 **	+4·9 **
Gafsa rock phosphate	1954	+2·6	+5·1 **
	1955	+3·2	+5·2 **
Standard error of increases ...		±2·01	±0·88

In both years superphosphate applied 2, 3 or 4 years earlier increased yields significantly; in 1958 (but not in 1957) Gafsa rock phosphate applied 2 or 3 years previously gave yields of barley similar to those from residues of superphosphate. Soil samples taken in 1958 were used in a glasshouse experiment (with Close) to measure the residual values of the phosphate fertilisers applied in 1954 and 1955. About 60–80% of the phosphate remaining in the soil from both superphosphate and rock phosphate was isotopically exchangeable and increased yield and phosphorus uptake by ryegrass to the same amount as did an equivalent amount of fresh monocalcium phosphate. The values of superphosphate and Gafsa rock phosphate 4 years after they were applied did not differ in either the glasshouse or the field experiment. A further field experiment, designed to last 6 or more years, was started to compare the residual effects of superphosphate, basic slag, Gafsa rock phosphate, potassium metaphosphate and several nitrophosphates with different water-solubilities. (Mattingly and Widdowson.)

A greenhouse experiment using ryegrass (done with Close) measured the residual value of superphosphate in acid (pH 5·0–6·0) and very acid soils (pH 4·0–5·0) taken from nine field experiments in Great Britain and Japan. The soils differed greatly in mechanical composition and in parent materials, and they had received from 50 to 450 lb. of P/acre. On average about 70% of the residual phosphate was isotopically exchangeable, values for individual soils varied from 36% for a soil from basalt, to 100% for soils from Silurian shales. The mean value is similar to that on acid soil at Rothamsted and is much higher than values for calcareous Rothamsted soils. The residues of superphosphate increased both yield and phosphorus uptake by ryegrass significantly with all soils except that from basalt. The residual value of superphosphate

was as great on acid volcanic ash soils from the Hokkaido Agricultural Experiment Station in Japan as on an acid soil from Rothamsted. The pH of the soils, and their mechanical compositions, were not correlated with the amounts of isotopically exchangeable phosphate they contained. (Mattingly and Kushizaki.)

Calcareous soils

In calcareous soils at Rothamsted about one-third of the residual phosphate from the continuous application of superphosphate remains isotopically exchangeable (*Rep. Rothamst. exp. Sta.* for 1957, p. 61), a considerably smaller fraction than in acid soils. Some of the factors were studied that influence the amount of exchangeable phosphate in soils from long-term experiments at Rothamsted and Saxmundham. The proportion of the residual phosphate that remains isotopically exchangeable increases with decreasing soil pH. Table 3 shows this effect, and that of continuous manuring with ammonium sulphate on some Rothamsted soils. Ammonium sulphate increased the proportion of residual phosphate in soils that remains isotopically exchangeable, even when soil pH is near 7·0. Applying magnesium and potassium sulphates annually for nearly 100 years to Barnfield has not changed the amounts of isotopically exchangeable P in the soil, either on plots without phosphate or on those that have superphosphate each year. Where nitrogen was given as sodium nitrate, both on Barnfield and at Saxmundham, it increased the size of the crops and decreased both the total amount of exchangeable phosphate and the proportion that remains isotopically exchangeable.

TABLE 3

Effects of ammonium sulphate and soil acidity on the percentage of residual phosphate in some Rothamsted soils receiving superphosphate that is isotopically exchangeable ("A") in glasshouse experiments

Field	Soil pH	Increase in "A" (mg. P/100 g. soil) from applying superphosphate in the field	Increase in "A" as % of increase in total P
No nitrogen:			
Barnfield	7·3	13·1	26
Hoosfield	7·2	27·4	35
Ammonium sulphate:			
Barnfield	7·3	25·7	42
Broadbalk	7·0	24·3	44
Agdell	6·1	8·1	48
Acid soils:			
Sawyers	5·0	5·0	78

On both the calcareous and the slightly acid Rothamsted soils, and on the calcareous Boulder Clay from Saxmundham, the uptake of P by ryegrass was closely correlated with the total amount of exchangeable soil phosphate. Phosphorus uptake was, however, about 20% greater per unit of exchangeable phosphate from the Saxmundham soils than from the Rothamsted soil. (Mattingly and Close.)

Comparisons of potassium fertilisers

Muriate of potash (containing 60% K_2O) supplies most of the potassium fertiliser used in the United Kingdom. There is no evidence that the chloride benefits crops, although chlorine is an essential micronutrient. With heavy dressings of potash, the chloride raises salt concentrations and may damage growth when fertilisers are applied too close to seed. To avoid this, and to improve quality, some potato growers, and many horticulturists, prefer to use potassium sulphate. Small amounts of potassium bicarbonate (containing 46% K_2O) intended as a fertiliser can now be obtained for experiments. Using bicarbonate removes the risk of injuring crops by the co-ion in potassium fertilisers, and it was compared with muriate of potash and potassium sulphate for potatoes. The yields at Rothamsted were:

	Tons of potatoes/acre
Without potash...	7·2
With muriate of potash	10·3
With potassium sulphate	10·6
With potassium bicarbonate	10·8

Bicarbonate gave the highest yield. The tops and tubers contained most chloride with muriate of potash and most sulphur with potassium sulphate. (Cooke, Widdowson and Williams.)

Potassium fertilisers increased yields in three out of six experiments on potatoes done on commercial farms. Yields from muriate and sulphate of potash did not differ consistently. (Widdowson and Penny.)

Concentrated fertilisers

Fertilisers may affect crops through the substances other than the N, P and K they supply. Other ions present increase salt concentrations and may damage crops or affect the intake of other nutrients. Some fertilisers may also be important sources of sulphur, calcium and magnesium. Compound fertilisers have become more concentrated recently. Greater concentration lowers cost to farmers by cheapening packaging, freight and spreading charges; concentrated fertilisers may be better than dilute ones provided they contain less of the useless ions that only increase salt concentrations in the soil, but they might be less satisfactory if the "diluents" in the less-concentrated materials supply plant nutrients. Concentrated fertilisers are therefore being compared with the older standard materials used in most of the field experiments done in this country.

Two concentrated fertilisers, prepared from ammonium nitrate, diammonium phosphate and muriate of potash were compared in 1959 with mixtures of ammonium sulphate, ordinary superphosphate (18% P_2O_5) and muriate of potash that supplied the same amounts of plant nutrients as the newer materials. In potato experiments the concentrated fertiliser contained 15% N, 10% P_2O_5 and 20% K_2O; all fertilisers were applied in the furrows before planting. For barley concentrated fertiliser (containing 20% N, 10% P_2O_5, 10% K_2O) was compared with a granulated mixture of ordinary ingredients (containing 12% N, 6% P_2O_5, 6%

K_2O); both fertilisers were combine-drilled. Table 4 summarises results at Rothamsted and Woburn.

TABLE 4

Comparisons of concentrated and " ordinary " fertilisers

	Without fertiliser	With ordinary fertiliser		With concentrated fertiliser	
		Single rate	Double rate	Single rate	Double rate
	Potatoes, yields in tons/acre				
Rothamsted ...	8·5	11·5	13·4	11·5	13·7
Woburn	4·0	6·7	7·1	6·6	8·0
	Barley, yields of grain in cwt./acre				
Rothamsted ...	14·4	27·6	37·7	27·6	37·5
Woburn	13·8	24·9	30·8	24·4	33·0

Yields of potatoes at Rothamsted and Woburn were identical from the ordinary fertiliser and its concentrated equivalent at the lower rate of dressing, but at the higher rate (1·5 cwt. N, 1·0 cwt. P_2O_5, 2·0 cwt. K_2O/acre) the concentrated material gave slightly higher yields at both centres. The two forms of fertilisers gave identical yields of barley at Rothamsted, but at Woburn concentrated material at the higher rate (0·66 cwt. N, 0·33 cwt. P_2O_5, 0·33 cwt. K_2O/acre) gave significantly better yields. (Cooke and Widdowson.)

THE VALUE OF PHOSPHORUS AND POTASSIUM RESERVES IN SOILS OF THE LONG-TERM EXPERIMENTS

Exhaustion Land experiment

The history of the Exhaustion Land and recent experiments on this site are described elsewhere in this Report (pp. 230–239).

Agdell Rotation experiment

The results of the Agdell Experiment and a description of its soils have been published (*Rep. Rothamst. exp. Sta.* for 1957, p. 252). The site has a wider range of fertiliser residues than the Exhaustion Land, and recent work was planned to value them and to compare methods of soil analysis.

In 1958 and 1959 Italian ryegrass was grown on half of each of the old Rotation Plots. All plots had nitrogen fertiliser for each cutting. Two silage cuts were taken in 1958 and three in 1959 (by Widdowson and Penny), total yields of grass and the amounts of P and K in the crops (determined by Williams) are shown in Table 5 for the two years together. The residues from manuring in the old Rotation Experiment increased yield of grass greatly in both years. In the two years, the PK-treated plots provided 13·7 lb./acre of P, and the NPK-treated plots 19·5 lb/acre of P, more than the old unmanured plots; the average total extra uptake from the four treated plots was 16·6 lb./acre.

The grass removed much K, and average uptake from the four treated plots in 1958 and 1959 together totalled about 160 lb. K/acre more than was taken from the old untreated plots. At these annual

rates of recovery (8 lb./acre for P and 80 lb./acre for K) grass would exhaust the fertiliser residues accumulated during the first century of the experiment completely in about half a century for P and about 20 years for K. (The size of these reserves is interesting, for they were built up by the residues from 4 cwt./acre of superphosphate and 3 cwt./acre of potassium sulphate given once in 4 years.)

TABLE 5

Total yields of grass and contents of P and K for all cuttings taken from the Agdell Experiment in 1958 and 1959

Manuring treatment in Experiment (1848–1951)	Rotation (clover or fallow)	Yield of dry grass (cwt./acre)	P in crop (lb./acre)	K in crop (lb./acre)
None	Clover	53	9·4	156
	Fallow	77	13·9	206
PK	Clover	103	23·6	320
	Fallow	110	27·2	322
NPK	Clover	111	28·8	346
	Fallow	121	33·5	376

The other halves of the Agdell Rotation plots each grew strips of barley, potatoes and sugar beet in 1959. Fresh dressings of superphosphate were tested on each crop to measure the value of the residues from the old phosphate dressings. Although the soil was in poor condition in spring 1959, and the summer was dry, the best soils gave satisfactory yields per acre with full manuring (30 cwt. of barley, 11 tons of potatoes and 15 tons of sugar beet). The responses to fresh superphosphate (summarised in Table 6) confirm that phosphate residue in the soil enough for barley is too little for

TABLE 6

Responses in 1959 to fresh dressings of superphosphate on site of Agdell Rotation Experiment

Manuring and rotation treatment in old experiment		Barley grain (cwt./acre)	Potatoes (tons/acre)	Sugar beet roots (tons/acre)
Responses to 1·0 cwt. P_2O_5/acre applied in 1959				
None	Clover	16·3	3·3	0·3
	Fallow	9·7	4·9	2·2
PK	Clover	5·8	2·6	0·5
	Fallow	0·3	1·9	0·0
NPK	Clover	−1·9	3·2	1·6
	Fallow	0·1	3·6	0·3

potatoes, even though the two crops usually take up very similar amounts of P. The full dressing of superphosphate tested in 1959 (1·0 cwt. P_2O_5/acre) gave higher maximum yields of barley and potatoes on the old Rotation Plots that had received phosphate from 1848 to 1951 than on the old untreated plots, an unexpected result, perhaps attributable to bad soil conditions and dry weather in 1959. Sugar beet gave little response to superphosphate, even on the very P-deficient soils of the unmanured Rotation Plots. (Johnston and Warren.)

Woburn Continuous Wheat and Barley experiments

The classical manuring treatments in these experiments stopped in 1927, but cropping was continued. The previous PK fertiliser treatments affected crop growth, but all yields were poor, and they were irregular because of weeds and soil acidity. The sites were surveyed in 1953 and 1954, chalk was applied to restore all the soil to pH 6, at which the experiments started in 1877, and the land was fallowed to destroy weeds. In 1959 winter wheat was grown on half of each plot and spring barley on the other half, all with nitrogen fertiliser. Most of the plots carried a uniform plant, and samples of the young crops had P contents that were related satisfactorily to soil analyses. Plans are now made to have micro-plot experiments with potatoes and barley on this site in 1960 to measure separately the residual effects of P and K fertilisers applied between 1876 and 1926. (Johnston and Warren.)

Manuring Experiments in Forest Nurseries

An account of twelve seasons' work (1945 to 1957) done in collaboration with the Forestry Commission is being prepared for publication, and it is hoped that it will be ready in 1961 (Benzian).

Phosphorus toxicity to yellow lupins

Conifers and green crops are grown in a rotation experiment at a nursery on very acid heathland soil near Wareham (Dorset). The older leaves of yellow lupins (*Lupinus luteus*) grown with fertiliser often die, as sometimes do whole plants. The most severely affected plants contain 2·2% P, and pot experiments at Rothamsted using Wareham soil confirmed that the damage increased with the amounts of monocalcium phosphate applied and with the P contents of the plants. At another nursery near Oxford, on less acid sandy loam, yellow lupins grew normally with the same fertiliser treatment as caused damage at Wareham. (Warren and Benzian.)

Magnesium in Crops and Soils

Measurements of the magnesium removed by crops and grass were obtained from experiments at Rothamsted and Woburn. Most of the crops examined remove from 4·5 to 6·5 lb. Mg/acre; potatoes at Rothamsted removed only 2·5 lb. Mg/acre, whereas lucerne and sugar beet removed more than 10 lb. Mg/acre. Permanent grass and temporary grass remove rather less than 10 lb. Mg/acre.

The hay crops from Park Grass in 1957 and 1958 were analysed to show the effects of chalk and K fertiliser on the percentage of Mg in the herbage. Where potassium was not supplied, chalk increased the percentage of Mg in the herbage in seven of eight comparisons, on average by about one-third. When potassium was given either as fertiliser or as farmyard manure, the % Mg in herbage was slightly decreased. Chalk and potassium may affect the percentage of Mg in herbage, wholly or in part, because they have changed the botanical compositions on the plots. Potassium has encouraged leguminous plants, which normally contain much Mg, whereas nitrogen has eliminated most of the legumes. Manuring and chalking

have also greatly changed the proportions of different grass species present. Magnesium fertiliser has not altered the effects of the chalk and potassium. One ton of local chalk contains about 10 lb. of Mg, so that the standard dressing, given once in four years, supplies about 18 lb. Mg/acre to the herbage (or 4·5 lb. each year), which is equivalent to about half the amount applied (10 lb. Mg/acre each year) as magnesium sulphate on the treated plots.

Rothamsted and Woburn soils contain about one-fifth as much Mg as K. Average values for Park Grass soils are 0·2% Mg and 1·1% K. The crops from some of the plots of Park Grass that receive only NP or N fertilisers show that the ratio of Mg : K in the crops is about 1 : 5·5. This is similar to the ratio of the total amounts of the elements in the soil, a result that might be expected from the "weathering" of the soil minerals if the Mg and K are closely associated in them. In the crops of the other Park Grass plots, however, the Mg : K ratio is less, varying from 1 : 7 to 1 : 8. (Warren and Smith.)

Arsenic in Soils

Arsenite has been used as a haulm killer for potatoes at Rothamsted and, as there was no information on its after-effects, arsenic levels in soils were measured. Arsenate, formed by oxidation of arsenite, interferes in the method of analysis generally used for small amounts of P in soil extracts, and special attention was given to this aspect of the accumulation of arsenic. Some of the plots of Broadbalk contain 12–15 p.p.m. of As; the Highfield Ley–Arable Experiment soils contain from 5 to 17 p.p.m. Stackyard field at Woburn has 25 p.p.m. and other Woburn soils contain from 10 to 19 p.p.m. of As. The amounts of soil arsenic dissolved by some of the solvents used for readily soluble soil phosphorus were determined. There were no measurable amounts of arsenic in extracts of Highfield and Woburn soils with 0·01*M*-$CaCl_2$, citric acid, acetic acid, hydrochloric acid and sodium bicarbonate solutions. The limit of detecting As under the conditions of these tests was 0·1 p.p.m.; this is sensitive enough for all but the $CaCl_2$ extracts, and with these it would be possible to add amounts of arsenic that would affect phosphorus values significantly. Citric acid solution extracted 2 p.p.m. As from Broadbalk soils, and acetic acid, hydrochloric acid and sodium bicarbonate dissolved 0·5 p.p.m. As. None of these amounts would affect the interpretation of phosphorus results for *normal* soils, but on very P-deficient soils, 0·5 p.p.m. As soluble in $NaHCO_3$ might be important.

The amount of arsenite used to destroy haulm is equivalent to about 3 p.p.m. of As in the surface soil. Both arsenite and arsenate react fairly rapidly with soil; in one test 5 p.p.m. of As was added and 60 hours later only 1 p.p.m. was extracted by citric acid, and calcium chloride solution did not extract a detectable amount. Using arsenite as a haulm killer in the normal way will not affect the citric acid, hydrochloric acid and acetic acid methods for determining readily soluble phosphorus in soils, partly because arsenic is rapidly fixed by the soil, and partly because large amounts of phosphorus are extracted relative to the amount of arsenic added.

With calcium chloride and sodium bicarbonate extracts the interference is likely to be small, because 2 μg. As are needed to give the same amount of colour as 1 μg. P in the method generally used to analyse small concentrations of P. Simple modifications to the method for phosphorus analysis to eliminate interference by arsenic are being considered. (Foale and Warren.)

Micronutrients in Crops and Soils

Molybdenum

The amounts of molybdenum in crops from Rothamsted and Woburn extend over the range 0·50–5 p.p.m. of dry matter. Because some lucerne at Rothamsted contained little Mo (0·1 p.p.m.), special attention was given to this crop. In reviewing the role of Mo in plant metabolism Reisenauer (*Soil Sci.* 1956, **81**, 237) recommended that leaves be analysed to diagnose deficiency instead of whole plants, because he found that the percentage of Mo in leaves was four times greater than in stems. He concluded that a response to Mo would not be expected when the leaves had more than 0·4 or 0·5 p.p.m. of Mo.

Leaves and stems of lucerne grown in the Ley–Arable Experiments at Rothamsted and Woburn had the following Mo contents:

	P.p.m. of Mo in dry matter	
	Leaves	Stems
Rothamsted		
Highfield	0·15	0·12
Fosters	0·78	0·76
Woburn		
Stackyard	0·34	0·20

The concentrations of Mo in the leaves and stems do not show the large differences reported by Reisenauer, but the levels in lucerne from the Ley–Arable Experiments in Highfield are well below the limit he sets for a sufficiency of Mo. Levels in the comparable experiment on Fosters Field are well above this limit; at Woburn the level is border-line. Samples of lucerne from two other experiments showed that P and K fertilisers did not modify the percentages of Mo in lucerne; the samples were taken at different times of the year and in different years, and they had between 0·3 and 0·6 p.p.m. of Mo. Other samples showed that the level of Mo in lucerne may change with the time of the year and with the amount of growth, but none of the variations from these two factors gave a high value for Mo in the lucerne of the Highfield Ley–Arable Experiment. Highfield soil may be deficient in Mo, and amounts in one or two other soils may be marginal. Field experiments testing rates of Mo are planned. (Warren and Foale.)

The effects of fertilisers and farmyard manure on micro-nutrients in arable crops at Rothamsted

A series of " reference plots " on Great Field IV at Rothamsted started in 1956 measure the effects of combinations of N, P and K fertilisers, and also of farmyard manure, on yields of wheat, barley,

clover, potatoes and kale grown in arable rotation in each year. Crop samples taken in 1956 were analysed for Cu, Mn, Mo and Zn to provide information on the uptake of these elements and to see whether manuring treatments affect the amounts of these micronutrients in the crops. N, P, K fertilisers and farmyard manure all depressed the percentages of Cu, Mo and Zn more often than they increased them, presumably because the treatments increased yields and " diluted " the micronutrients in the harvested crop, but the effects were not consistent. Mn contents were usually raised by all the manurial combinations tested. In most of the comparisons all crops (except kale) grown with farmyard manure removed more micronutrients than did crops with full dressings of NPK fertilisers, because farmyard manure gave higher yields than fertilisers. Kale grown with NPK fertilisers yielded better and removed more Cu, Mn, Mo and Zn than kale treated with farmyard manure. Table 7 shows the amounts of the elements removed by the five crops.

TABLE 7

Total amounts of micronutrients removed by five crops grown on the Rothamsted Reference Plots in 1956

	Without manure	With NPK fertiliser	With farmyard manure	With farmyard manure + fertiliser
	Amounts of elements in g./acre			
Copper ...	58	118	148	147
Manganese ...	334	704	846	1015
Molybdenum ...	3·0	5·4	4·7	4·5
Zinc	295	541	601	743

The total amounts of these micronutrients in the surface soil are compared below with the amounts removed by the five crops together from plots treated with farmyard manure and fertilisers.

	Total amounts in soil	Amounts removed by five crops
	lb./acre	
Cu	52	0·3
Mn...	2800	2·2
Mo	2	0·01
Zn	220	1·6

If the total amounts present become available to crops these reserves of micronutrients in the top-soil will last for many years of cropping.

The dressings of fertilisers used supplied less micronutrients than any one crop removed; in contrast, farmyard manure replaced as much Cu, Mn and Mo as was removed by the five crops, and nearly as much Zn.

Individual crops removed varying quantities of micronutrients. Clover removed more of each of the elements than did wheat, barley or potatoes. Both clover and kale removed much more molybdenum than the other crops. (Williams, Stojkowska, Cooke and Widdowson.)

Uranium in Crops and Soils Dressed Frequently with Superphosphate

Rock phosphates contain about 0·015% of uranium, and superphosphate made from them is slightly radioactive. Soils and crops from several long-term experiments at Rothamsted having superphosphate for many years were analysed for uranium by Mr. G. H. Smith at the National Chemical Laboratory, Teddington, Middlesex. The uranium content of unmanured soils from Broadbalk (Permanent Wheat) and Hoosfield Exhaustion Land (now in barley) was 2·5 p.p.m. U, and there was no evidence that annual applications of superphosphate to Broadbalk (3·5 cwt./acre since 1843) or to the Exhaustion Land (about 3 cwt./acre from 1856 to 1901) have increased the amount of uranium. Cereal straws from both experiments contain $<0{\cdot}02$ p.p.m. U; superphosphate did not increase the uranium content of the crop. (Mattingly.)

Analytical Work

Organic carbon in soil

Determining organic carbon in soils by oxidising with dichromate and titrating the unused dichromate is fast and simple, and inorganic carbonates do not interfere. Many modifications of this basic procedure have been proposed, and several of these were tested. Oxidation of soil organic matter was not complete in any of the methods investigated, nor was 1 equivalent of dichromate oxygen found to be equivalent to 3 g. carbon in all soils. "Carbonised" carbon in materials like coal, soot, graphite and charcoal was partially oxidised so that the titration methods tested could not discriminate between "carbonised" material and soil organic matter. Oxidation of soil organic matter by potassium persulphate was tested with the hope of developing a more selective procedure. The method devised gave quantitative results with sucrose, glycine, oxalic acid, resorcinol, cellulose, chitin, lignin, wheat straw, dried grass, a compost and a range of non-calcareous soils. 2–5% of the carbon in bituminous coal was recovered, 0·2–2% from anthracite and 0–0·5% from graphite. But 40–45% of the carbon in wood charcoal was recovered, and even more from soot; persulphate oxidation therefore is not a promising way of distinguishing soil organic matter from other carbonised materials. (Bremner and Jenkinson.)

Scintillation counting of ^{14}C.

A method was needed to measure precisely the activity of carbon dioxide evolved when incubating soil with labelled plant material. A black dye was dissolved in the active solution, which was then placed in a cylindrical cell having a base covered with a thin film of plastic phosphor. The light pulses from the cell were counted in a scintillation counter. The results were independent of the volume and colour of the liquid in the cell, and of the chemical form of the carbon. Dissolved substances such as 10% solutions of glycine, sodium acetate, sucrose, sodium pyrophosphate and sodium sulphite had little effect and altered the count rate by less than 5%. Acid

solutions had to be neutralised before being put in the cell. Although the method is rapid and reproducible, it is inefficient, and for lower activities a liquid scintillation method based on the absorption of CO_2 in caesium hydroxide, which is being developed, is more promising. (Jenkinson.)

Forms of nitrogen in soils and plants

Work on nitrogenous constituents of soils and plants is hindered by lack of rapid and specific methods of determining different forms of nitrogen. When using labelled nitrogen the methods of analysis must give a product that can subsequently be analysed by the mass spectrometer; the favoured product is ammonia, which is converted to gaseous nitrogen by treating with alkaline hypobromite. To meet these requirements, progress was made with methods for determining ammonium-, nitrite-, nitrate-, hexosamine- and α-amino-N. The different forms of nitrogen are converted to ammonia, which is determined by steam distilling for 3–4 minutes using a specially designed micro-distillation apparatus. Ammonium-N is determined by steam distilling with magnesium oxide, and nitrate-N by continuing the distillation after adding titanous sulphate. When nitrite-N is present one sample of the test solution is treated with sulphamic acid to destroy nitrite, and a duplicate sample treated with acidified permanganate to oxidise nitrite to nitrate, the excess permanganate being destroyed with acidified ferrous sulphate. Both samples are distilled with MgO, and nitrite-N is estimated by difference. Hexosamine-N is determined from the ammonia liberated by steam distilling with a phosphate–borate–thiosulphate mixture (pH 11·2). α-amino-N (amino-acid-N) is determined by treating with ninhydrin at pH 2·5 for 10 minutes at 100° and estimating the ammonia liberated by steam distilling the ninhydrin reaction product with the mixture used in the method for hexosamine-N. These methods are simple and rapid, and the same apparatus and standard solution are used in each. They are not affected by inorganic salts likely to occur in plant or soil extracts and appear to be highly specific. With over fifty nitrogenous compounds, including amino-acids, purine and pyrimidine bases, and labile compounds such as glutamine, asparagine, glucosamine and urea, none yielded ammonia or volatile base under the conditions of the method used to determine ammonium-N. With plant extracts, results by this steam distillation technique agreed closely with those by a low-temperature vacuum distillation method of determining ammonium-N in the presence of labile nitrogen compounds. Ammonium-, nitrite- and nitrate-N added to soil and plant extracts was recovered quantitatively. The method of determining α-amino-N gave quantitative results with 19 of 26 amino-acids tested; low results were obtained with cystine, cysteine, tryptophan, proline and hydroxyproline, and high results with arginine and ornithine. Attempts (with Dr. M. Salomon) to determine α-amino-acids by estimating the ammonia formed in their reaction with peri-naphthindan-2 : 3 : 4-trione hydrate failed. (Bremner.)

Nitrogen in grass

Three methods of determining NH_4-N in water extracts from grass were compared. The microdiffusion method used by Bremner and Shaw (*J. agric. Sci.* **46**, 320) gave high values because ammonia was released from labile nitrogen compounds by enzyme action during the 40-hour incubation used. The new method developed by Bremner, and described above, agreed well with the established method of G. W. Pucher, H. B. Vickery and C. S. Leavenworth (*Ind. Engng Chem. Anal. Ed.* 1935, **7**, 152). (Nowakowski.)

PEDOLOGY DEPARTMENT

A. Muir

Dr. Ya. Rusko, an exchange student from the U.S.S.R. (Kiev), spent nine months between the Pedology and Plant Pathology Departments. Dr. S. P. Mitra (Allahabad) has now gone to the United States. Instruction in X-ray techniques was given to Mr. J. W. Vail (Tanganyika) and Dr. A. K. Helmy (Egypt), and Dr. J. S. P. Yadav (Dehra Dun) spent some time studying spectrography. Mr. C. B. Wells (C.S.I.R.O.) will work with C. Bloomfield on carbonate movement in soils.

Mineralogy

Expanding lattice minerals

(1) In the course of characterising the weathering products of picrite from Shropshire (*Rep. Rothamst. exp. Sta.* for 1957, pp. 65–66), two unusual types of expanding-lattice minerals were studied. A variety pseudomorphous after and derived by weathering from fibrous chlorite occurs in fairly large amounts in the (B)/C horizon of a brown earth at Woodgate, ½ mile south of Corndon Hill. The fibrous character and swelling properties of minerals classified as saponite, bowlingite and diabantite by other workers were demonstrated, and fibre photographs of bowlingite (Cathkin Hills) taken here show a general resemblance to those of the Woodgate soil mineral, but with differences in detail. A lamellar mineral occurring at the base of the soil seems very similar to the layer-lattice silicate found to be a constituent of iddingsite (Brown and Stephen, *Amer. Min.* 1959, **44**, 251–9), giving a disordered stacking of layers, the only regularity, in addition to the parallel and equidistant stacking of the silicate layers, being the parallel alignment of the hexagonal *a*-axes of the half-layers of the mineral. A distinction from the iddingsite material is that the soil mineral expands with glycerol. Various crystallographic considerations suggest that both the fibrous and the lamellar minerals owe their crystallographic order to the inheritance of undisplaced structural units from their parent minerals. The study of such pseudomorphs should give structural information about clay minerals that could not otherwise be easily obtained (see abstract 3.4). (Brown and Stephen.)

(2) An expanding layer-lattice mineral from Baluchistan, Pakistan, was identified as an allevardite. Chemical analysis confirmed that it was a sodium aluminium silicate and contained only traces of other metal atoms. X-ray-diffraction patterns were identical with those of the type mineral from Allevard, indicating a mineral with a structure composed of silicate sheets with a thickness of 19·4 Å., separated by layers of intercalated water or organic molecules. The structure was described by Brindley (*Amer. Min.* 1956, **41**, 91). Both the Baluchistan and type allevardites were formed as skin-like aggregates of flakes, and specimens of natural minerals gave hkl reflections on X-ray-diffraction photographs.

The appearance of these reflexions depended on the previous dispersion state of the specimen, and discrete reflexions were replaced by diffraction bands in patterns from specimens made from suspensions of fully dispersed flakes.

Measurements of the effect of charge density on lattice expansion of allevardite, beidellite and vermiculite showed that the volume occupied by inter-layer water or organic molecules decreased as the charge density of the expanding layers increased. With inter-layer ethylene glycol the contraction of the lattice was accompanied by reorientation of the glycol molecules. The beidellite had a charge density of $0{\cdot}46/Si_4O_{10}$, intermediate between those of the other two, and showed a complex arrangement of ethylene glycol.

The electron microscope showed that the type mineral was composed of large flakes with folded edges and narrow folded ribbons. The electron micrographs showed that the ribbons were flattened helical spirals, and thus had been present as helices in suspension. B-allevardite was composed of flakes of equally large area, 10–40 μ were characteristic dimensions, but had no ribbons, and the flakes were not folded.

The thickness of the thinnest flakes of allevardite and beidellite, freed from finely dispersed material, were measured directly from shadowed electron micrographs. The thinnest flakes of allevardite, calculated from shadow lengths, were 18 Å. thick, and those of beidellite, 14 Å., which is direct evidence that flakes consisting of double 2:1 units for allevardite and single 2:1 units for beidellite were present in suspension. Other experiments demonstrated that allevardite flakes were easily dispersed completely, but with beidellite, in common with other smectites, this was rarely achieved. Increase in the thickness of the metal shadowing in the micrographs increased the apparent flake thickness, and this in part explained the discrepancy between the thickness of beidellite flakes measured from micrographs, 14 Å., and from X-ray-diffraction patterns, 9·7 Å. The existence of the double-layer structure in allevardite was demonstrated directly in one electron micrograph where the shadows of two 9-Å. edges merged at either end to form single shadows of an 18-Å. edge. Double edges were common in the folded allevardite, and resulted from cleavage along the mica-like interface relieving the stresses developed during the flattening of the helical ribbons. (Weir.)

Clay Mineralogy

Several visitors were given instructional courses in X-ray diffraction and its application to clay-mineral studies. To lessen the work involved in future, a series of instruction sheets is being prepared. Eventually it will cover the basic concepts and applications of X-ray diffraction to clay mineralogy, and it will both save time now and provide a permanent record of the course. (Brown.)

G. Brown is editing the new edition of *X-ray Identification and Crystal Structures of Clay Minerals* published by the Mineralogical Society and is contributing the chapter on " Other Minerals ".

Soils and sediments

Many clay fractions from soils and sedimentary rocks were analysed. They include samples from Tanganyika (10), Kenya (2), Borneo (15), Basutoland (7), Sudan (6), Jugoslavia (7), Uganda (4), Malaya (4), Swaziland (19) and Britain (84). Of these, 38 were examined under the Colonial Office scheme for analytical assistance to overseas territories. Clay fractions from soils and clay minerals being studied by members of Rothamsted staff and others were also examined.

At the suggestion of P. H. T. Beckett (Oxford) some samples of Cretaceous rocks laid down under desert conditions were examined for palygorskite, but none was found.

After the interesting results on the Downtonian from the West Midlands reported last year (*Rep. Rothamst. exp. Sta.* for 1958, p. 63) many specimens of Old Red sediments were collected from that area. The variability of the clay mineralogy, both laterally and vertically, is being studied in the hope of relating it to sedimentation conditions. The study will also provide useful information on the parent materials of a group of very fertile soils. The specimens so far examined show that the clays are fairly well crystallised. (Du Feu.)

Further investigation of the Ukiriguru catena (*Rep. Rothamst. exp. Sta.* for 1958, p. 63) showed that all the soils of the sequence had granite as their ultimate parent rock. The soil clays in the upper part of the catena are relatively rich in mica, which does not occur in a specimen of weathered granite from the tor. Kaolin is the only clay mineral identified in the rock material. The leaching conditions on the tor are probably such that potash set free from feldspars is immediately removed, thus preventing the formation of mica, which can, however, accumulate in the soils below. (Muir, Du Feu and Stephen.)

Apparatus

Preliminary work showed that the X-ray diffractometer can be adapted for use as a spectrometer for X-ray fluorescence analysis by altering the collimation system. In view of the undoubted importance of this method of analysis, advantage was taken of the adaptability of the instrument to gain some experience of the method.

An attempt was made to build a suitable camera for determining the iron content of materials by non-dispersive X-ray fluorescent analysis. The apparatus would be simpler and less expensive than that normally used. The fluorescent radiation was measured by photometering the X-ray film exposed in the beam. Unwanted scattered radiation interferes seriously, but by using suitable filters and Geiger counters it should be possible to surmount the difficulties.

In modifying the old electron microscope for pedological studies, the first requirement was to obtain an electron beam as narrow as possible. Moderate success was achieved in converting the machine into a two-lens X-ray projection microscope, and a fairly good definition obtained. The present electron beam is in the region of 10 μ, and further work will be done to bring this to 1 μ or less,

ocused as far outside the lower lens as possible. This will then nable the X-ray microscope to be used as an electron probe.

Petrography and Micropedology

Latosolic red soils and an associated yellow soil from Mount Zomba, Nyasaland, are derived mainly from syenite. The soils, however, have somewhat different mineralogical compositions and, in particular, the yellow soil contains more unweathered primary minerals, e.g., feldspars and hornblende, than the red. This suggests that the soils differ in their weathering regime, or that the red have been weathering for longer. The former possibility seems the more likely, as the soils appear to have a catenary relationship with the red soils occupying the higher topographic sites and the yellow soils occurring in depressions. The humus forms also indicate a difference in weathering regime, mull humus being associated with the red soils, whereas the yellow has a mull-like moder humus cover. Thin-section studies show the breakdown of primary minerals to clay-sized materials, but give no evidence of any translocation of clay within the profiles. This contrasts with red-soil formations from Kongwa and Nachingwea in Tanganyika, derived from material of Basement Complex origin, in which there is evidence of clay migration and its accumulations on the walls of pore spaces (cf. *Rep. Rothamst. exp. Sta.* for 1958, p. 62). The red soils from Zomba appear to correspond closely to the (lateritic) roterdes as defined by Kubiena (*Soils of Europe,* 1953). (Stephen and Osmond.)

Physical Chemistry of Soil Minerals

Optical properties of clays

The work described last year was continued. In the study of methods to determine the birefringence of clay aggregates, an improved microtome technique enabled uniform clay sections of known thickness to be cut. The birefringence of sections can thus be estimated directly from their optical retardation. With simplification the method is suitable for routine use. Optical studies of the highly disordered hydrous micas showed that these minerals form mixed layer complexes with aromatic molecules and up to half the layers expand. Evidence is accumulating that these expanding layers resemble those of montmorillonites more than those of vermiculites; i.e., if the expanding part of the hydrous mica crystals were regular, they would give X-ray spacings of 18 Å. rather than 14 Å. with glycerol.

Surface studies on clays

Work on several topics mentioned in previous reports was completed, and the results are being prepared for publication.

The increasing use of the B.E.T. apparatus to measure surface areas made it desirable to modify the somewhat tedious procedure. A simple and compact apparatus was designed and built and is proving most satisfactory. Forty to sixty samples can now be measured using one container of liquid nitrogen over a period of a

week, and its accuracy is not significantly less than the more complex unit. The apparatus is being used to study the finest inorganic fractions of soils. (Greene-Kelly.)

Clay mineral synthesis

The apparatus for high-pressure synthesis was much more reliable this year and a series of experiments at 250° and 350° C. yielded products in which crystalline phases could be identified by X-ray analysis, including kaolinite, montmorillonite, analcite, paragonite, boehmite, chlorite and amesite. The products were also examined by differential thermal analysis and by electron microscopy and one by electron diffraction—a method it is hoped to use more often in the future. The products and any particle size fraction thought likely to be a nearly pure mineral, such as the coarse and fine fraction of one preparation which were almost pure paragonite and analcite respectively, were analysed chemically.

The paragonite formed differed from the 2*M* natural material and was later shown to resemble synthetic 1*M* material prepared by Yoder and Eugster (Eugster private communication). One of the minerals formed from silica–alumina gel and magnesium hydroxide had an X-ray-diffraction pattern similar to kaolinite, but with a basal spacing of 7·04 Å., suggesting the presence of amesite (Brindley, Oughton and Youell, *Acta Cryst.* **4**, 552, give 7·00 Å.; Steinfink and Brunton, *Acta Cryst.* **9**, 487, give 7·02 Å.). (Rayner.)

Spectrochemistry

Determinations are being made on the general levels of minor elements occurring in selected sedimentary deposits and in soils derived from them, with attention to the distribution of the elements in the different particle-size fractions. Analysis of the liquids used during mechanical fractionation, and of the fractions themselves, showed that losses to solution are usually small. In the soils studied, losses of Ba, Cr, Ga, V and Zr were negligible; this was also so with Sr in non-calcareous soils. Rather greater losses may occur with Co, Cu, Mn, Ni, Pb and Zn.

In a London clay soil the concentrations of Co, Cr, Cu, Fe, Ga, Mn, Ni and V tend to increase down the profile. The bulk of these elements resides in the clay fractions, and their concentrations in this remain fairly constant; but in the sand and silt fractions they increase considerably with depth. The movement of these elements in this soil seems independent of clay movement, and their accumulation at lower levels takes the form of a deposit on the coarser particles and not on the clay. This is confirmed by a strong Fe staining of the sand grains (*cf.* Soil Chemistry, below).

A comparison of levels of organic carbon in specimens of London clay and Lower Lias shales suggests why grey London clay weathers brown and Lias shales do not. Measurements on many specimens of Lias shale showed that in most organic C was well above 1% and in many above 5%. No specimens of grey London clay, however, contained more than 0·5% organic C; furthermore, in a London clay soil, brown clay at 11 feet contained 0·1%. This suggests that where clay or shale contain enough fossil organic matter, reducing

conditions are maintained, as in the Lias; but the London clay seems to contain too little to keep all the iron in the ferrous form.

Some spectrographic measurements were made on suspected heavy metal contamination in sewage sludge. Several had abnormally high levels of Zn, Cr and Ni, and it seems the trouble these elements caused was aggravated by the exceptionally dry summer increasing their concentration in the residual soil moisture. (Le Riche and Burnett.)

Soil Chemistry

The effect of soil waterlogging

The ratio of soil to water in a flooded soil profoundly affects the extent to which iron compounds are converted to water-soluble forms. After 2–3 weeks incubation with a large excess of water, the solution may contain amounts of iron in excess of 1% of the weight of the original soil; incubation of the soil at about water-holding capacity converts only a fraction of this amount of iron into a water-extractable form. At capacity, however, extraction with molar ammonium acetate solution at pH 7 removes a further quantity of iron, and yet more is removed at pH 3. The amount removed at pH 3 is commonly the greater part of the total amount rendered soluble, and with some soils the total extractable iron is comparable with the amount dissolved by incubation with a large excess of water. Nickel and cobalt behaved similarly in experiments on soils containing abnormally high concentrations of these elements.

All the iron rendered soluble might be removed from a soil incubated at low water content by prolonged leaching with water, because extraction of field samples of sulphide-free gley soils at pH 3 yields very little iron, but experience with laboratory preparations indicates that, if this is so, the leaching would take a considerable time.

Considerable difficulty was experienced in obtaining field samples of gley soils free from ferrous sulphide, or excessive amounts of reprecipitated ferric oxide, and no completely suitable material has so far been found. Results obtained with the least unsuitable soils indicate that very little of the residual iron is present in the ferrous form.

The mobilisation of minor elements in flooded soils was further studied. The availability of soils containing appreciable amounts of particular minor elements has dictated the choice of elements studied. Mn, Zn, Pb, Ni, Co, Cu, Cr and Mo are mobilised to various extents and, as with iron, whereas some of the solubilised material can be extracted with water, additional amounts can be leached from the incubated soil by a solution of ammonium acetate. Mo behaves differently from the other elements studied, and less is extracted at the lower pH value.

Copper oxide is readily dissolved by aqueous grass extracts, and the process appears to be non-biological; in fact, the presence of appreciable amounts of Cu appears to inhibit microbiological action, and thus largely prevents the solution of other elements. Increasing the amount of fermentable plant material in the reaction mixture greatly decreases the amount of copper mobilised. This anomalous

effect appears to result from the sorption of dissolved Cu on the insoluble fraction of the plant material.

Only little Cr dissolved when soil containing appreciable quantities of chromite were flooded, perhaps because of the refractory nature of chromite rather than of an intrinsic property of chromium.

Reoxidation and drying precipitates the bulk of the mobilised iron, and the minor elements are co-precipitated with the ferric oxide thus formed; however, appreciable quantities of the minor elements may still be extracted by neutral ammonium acetate—in general, more than can be extracted from the original soil. (Bloomfield, Greet and Ng Siew Kee.)

SOIL MICROBIOLOGY DEPARTMENT

P. S. Nutman

R. Cooper returned after ten months at the Timiryazev Academy, Moscow, and other research centres in the U.S.S.R. Prof. J. M. Vincent of Sydney University worked for eight months on the fluorescent antibody technique. Dr. B. M. Gupta of the Central Drug Research Institute, Lucknow, came in October, to study *Rhizobium* genetics and bacteriophage. Through the International Association for the Exchange of Students for Technical Experience, E. Klar of the Technical University, Charlottenburg, Berlin, spent six weeks helping N. Walker. D. Gareth Jones from the Welsh Plant Breeding Station, Aberystwyth, studied techniques for two weeks with the Rhizobium group. A. H. Gibson returned to the Division of Plant Industry, Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia, in April, and J. N. Parle to the Rukuhia Soil Research Station, New Zealand, in October; both were awarded the Ph.D. degree of the University of London.

Work on soil fungistasis, the streptomycin-resistant flora of the rhizosphere, the ecology of micro-organisms decomposing 2 : 4-D, the microbiology of earthworm gut and cast and certain aspects of the physiology of infection by nodule bacteria was stopped or suspended.

Work started on the continuous culture of *Nitrosomonas*, the nitrogen-fixing species of bacteria and fungi, the influence on yield of the inoculation of crop plants with *Azotobacter*, the possible transmission of soil-borne viruses by fungi, the microbial decomposition of triazine weed-killers in soil, fluorescent antibody reactions in *Rhizobium* and the glutamine and asparagine content of clover-root nodules.

Nitrification

A continuous culture apparatus, like that developed at the Microbiology Laboratory at Porton, was made by N. Walker and F. A. Skinner for work on nitrification. It embodies automatic control of temperature and pH, and the rate of aeration and medium flow is controlled and measured.

With a clear chemically defined medium (*Rep. Rothamsted exp. Sta.* for 1957, 77) *Nitrosomonas europea* was grown in continuous culture to give cell populations exceeding 900 millions/ml., thus giving gram quantities of dried cells. A cytochrome-like pigment was extracted from such cells, and partially purified; its absorption spectrum closely resembles that of mammalian cytochrome *c*.

When stored at −18° C. cells of *Nitrosomonas* grown in continuous culture rapidly lose their capacity to oxidise ammonia. A rapid fall in pH within the cells seems partly responsible, and washing and storing in buffer solution decreases the loss. (Walker.)

The limited growth of *Nitrosomonas* in flask culture is not increased by organic compounds or by molybdenum. Sodium chloride ($M/6$) and $M/25$ sodium sulphate retard growth, but high concentrations of nitrite are tolerated at pH 8·4; $M/12$ nitrite retards growth, $M/6$ is lethal. A method for counting *Nitrosomonas* and *Nitrobacter* in soil was developed. (Meiklejohn.)

Nitrogen fixation by free-living bacteria and fungi

Some nitrogen-fixing micro-organisms other than *Azotobacter* and *Clostridium* were isolated from soil. These fix nitrogen much more slowly than do *Azotobacter* in culture; they are, however, more abundant in soil and possibly of greater significance. Work started on fixation in the rhizosphere of wheat plants inoculated with a strain of *Aerobacter aerogenes* and an *Alternaria* sp. (which fixed 2·5–3·5 mg. N/g. glucose dissimilated in pure culture). Apparent nitrogen fixation was consistently greater in the inoculated cultures (as preliminarily reported for *Aerobacter* in *Rep. Rothamsted exp. Sta.* for 1958, 71). Experiments were done with wheat seedlings inoculated with *Aerobacter*, but fixation could not be established because of the difficulty in obtaining a true nitrogen balance sheet. Similar experiments with *Azotobacter* inoculated into water cultures of wheat showed higher fixation; this did not benefit the wheat.

Heavy inoculation of *Aerobacter* into unsterilised soil, with or without glucose and mineral salts (other than N-containing compounds) did not increase soil nitrogen, or yields or nitrogen content of plants. (Brown and Jackson.)

Work on the culture of *Aerobacter*, *Alternaria* and *Azotobacter* in the plant rhizosphere showed that plant growth was affected independently of yield. *Aerobacter* stunted wheat roots and suppressed tillering in water culture. In soil *Alternaria* inoculation had a similar but short-lived effect on tillering. At 5 weeks, tillering on inoculated plants was 68% of controls, at 7 weeks 92% and at 9 weeks 98% of controls. (Brown and Jackson.)

Inoculation of soil with Azotobacter

Russian claims that inoculation of soil with *Azotobacter* increases crop yield were studied in pot experiments. Freshly isolated strains of *Azotobacter chroococcum* were used and a range of crop plants and conditions of growth and manuring examined. Inoculation sometimes increased yield significantly, and apparently independently of added nitrate. However, the results were inconsistent and will be reported in more detail when the conditions governing their reproducibility are better defined. (Barford and Burlingham.)

The streptomycin-resistant bacteria of the rhizophere

Studies on the streptomycin-resistant bacteria of the rhizosphere ended when earlier results (*Rep. Rothamsted exp. Sta.* for 1957, 79) were confirmed in experiments with designs better suited for statistical treatment. Control samples were taken from planted pots subjected to the same fluctuations in moisture content as the rhizosphere samples. The separate effects of rose-bengal and streptomycin were assessed. (Brown.)

Anaerobic decomposition of cellulose and formation of methane

The soil bacterium that decomposes cellulose anaerobically (*Rep. Rothamsted exp. Sta.* for 1958, 68) was compared with other strains isolated similarly and with the type strain of *Clostridium cellobioparum* Hungate obtained from Dr. R. E. Hungate's laboratory, Davis, California. The anaerobic methane-producing bacteria able to use organic acids (especially formic and acetic) produced from cellulose by anaerobic cellulose-decomposers are now being studied. These grow very slowly and are strictly anaerobic, and work was confined to the technique of isolation and culture. (Skinner.)

Mechanism of transmission of soil-borne viruses

The possible rôle of fungi in the transmission of beet ringspot and tobacco necrosis was studied in collaboration with B. D. Harrison (Plant Pathology Department). The root surface fungi of susceptible seedlings grown in infective and non-infective soils from different localities showed no consistent differences. The infection of roots by tobacco necrosis virus was compared in sterile seedlings and seedlings infected with various fungi. (Jackson.)

The metabolism of glutamine and asparagine in root nodules

While at the Timiryazev Academy, Moscow, R. Cooper studied methods of estimation of small amounts of glutamine and asparagine using methods that involved chromatographic separation of amides and their hydrolysis and estimation by Conway titration. The sensitivity of the method is limited by ammonia contamination of chromatography paper, which can be largely overcome by washing with 80% acetone containing 0·002*N*-NaOH, but not with aqueous alkali.

This technique can measure the glutamine and asparagine content of 30 mg. fresh weight of nodules from clover. Effective nodules contained more of these amides than did ineffective nodules, and glutamine concentration increased faster when effective nodules were inoculated with ammonium sulphate. (Cooper.)

Application of the fluorescent antibody technique to quantitative studies with Rhizobium

The possibility of using antibody conjugated with fluorescin to distinguish between individual cells of serologically different strains of *Rhizobium* was studied to see whether it could be applied to the study of growth and strain competition outside the root and to the mechanism of infection. The technique works qualitatively, particularly when unspecific labelled anti-rabbit serum is reacted with the specific serum but is not refined enough for quantitative work. Accurate comparison of dark-ground with dark-ground fluorescent counts requires very good optical equipment. (Vincent.)

Clover root-hair infection in agar and in soil

The early stages of infection of the clover root in soft agar (using the Fåhraeus slide technique) and in finely structured raw soil were compared. Although the sampling of soil-grown seedlings makes

observation less accurate, the pattern of infection was shown to be the same in inoculated soil and in agar. Infection in both occurs in two clearly defined stages, and the rate of infection depends on host species and the inoculated strain. In uninoculated soil, infection takes about a week longer, but then occurs at the same rate as in uninoculated soil. The uninoculated soil and the seedling rhizosphere contained many viable Rhizobia. Experiments are being done to determine more precisely how infection of the root hair is influenced by rhizosphere population of nodule bacteria, in attempts to study what "soil factor" delays infection in uninoculated soil. (Lim.)

Host genetics of symbiosis

Red clover plants showing different responses to a phage-induced mutant of the ineffective strain "Coryn" were crossed. (*Rep. Rothamsted exp. Sta.* for 1958, p. 73). Crosses within selections that produce ineffective nodules bred true, those between effective and ineffective types gave mixed progeny, and most but not all offspring of crosses within effective selections were effective. Tests of these plants with the parent strain Coryn showed a similar pattern of response, but some of the crosses contained fewer effectives. With other classical effective and ineffective strains of bacteria the selected lines behaved like unselected red clover. The results suggest that effectiveness towards Coryn is controlled by a dominant host factor or complex.

This genetic factor possibly first appeared in commercial late-flowering Montgomeryshire red clover about 1954. Some local strains of Swedish red clover seem to have the factor for effectiveness, some not. (Kleczkowska.)

Work on variation in symbiotic effectiveness in subterranean clover, begun in Australia, ended. All the 15 isogenic subterranean clover varieties examined depended basically on the same genotypic control of nitrogen-fixation and assimilation, in spite of great differences in other properties. Hybridisation between varieties led to marginally higher yields in F_2, which declined in F_3 and was then lost. These small differences could not be maintained by selection and further hybridisation. Work continued on inheritance of nodule size and abundance in subterranean clover and on selection for ineffectiveness in red clover when inoculated with a normally effective strain. (Nutman.)

BOTANY DEPARTMENT

D. J. Watson

Gillian N. Thorne returned from Ottawa, where she spent fifteen months as a Post-Doctorate Fellow of the National Research Council of Canada. Dr. Waclawa Maciejewska-Potapczyk left at the end of August to visit other research institutes before returning to Poland. Miss A. V. Delap of East Malling Research Station came in May to spend six months in the department, and G. J. Leach, who holds a post-graduate scholarship from the Ministry of Agriculture, Fisheries and Food, joined us in October.

Joan M. Thurston was invited to speak at the meeting of the International Research Group for Weed Control at Stuttgart in March, and was asked to identify wild oats from the participating countries. She also attended the German Weed Control Conference that followed the international meeting. E. C. Humphries and D. J. Watson went to the IXth International Botanical Congress at Montreal and visited plant-physiological laboratories in Canada and U.S.A.

A new glasshouse for work on weeds, a covered floor for preparing soil for pot-culture experiment and a store for pots and other equipment were completed in October. Other additions were two thermostatically-controlled cabinets with artificial lighting for growing uniform test plants.

Physiology of Growth

Much of the laboratory work was concerned with the physiology of leaf expansion, because previous work showed the importance of leaf area as a determinant of the yield of field crops. In particular, work on gibberellic acid (GA) has continued, both because it affects leaf size when applied externally to plants and because there is evidence that a gibberellin-like substance is a normal constituent of leaves and controls their growth. Effects of GA and other growth substances were studied in growing tissues other than leaves. Changes in phosphorus compounds and related enzymes were studied with the help of Dr. Potapczyk, a specialist in this subject. The new growth cabinets were used to find the best form of lighting for the controlled environment rooms being equipped in the West Building. This work showed some unexpected effects of light quality on growth, which were further studied.

Interaction of gibberellic acid and nitrogen supply

Previous work (*Rep. Rothamst. exp. Sta.* for 1958, p. 75) showed that spraying potato plants with solutions of GA increased their leaf area. Plants with a high initial nitrogen supply showed at first a corresponding increase in dry matter production, but later the photosynthetic efficiency of the leaves, measured by net assimilation rate (E), was depressed, and the final yield was similar to that of unsprayed plants. From the outset spraying with GA decreased the dry weight and E of plants poorly supplied with N.

Analysis of material from the 1958 experiment showed that spraying did not affect nitrogen uptake, so that increase in leaf area was accompanied by a decrease in nitrogen content per unit area of leaf and per cent of dry matter in the high-N plants whose dry weight was increased by spraying. There was little change with time in N per unit area of leaves of low-N plants, but there was a steady fall in high-N plants, so that ultimately leaves of sprayed high-N plants had nitrogen contents similar to those of unsprayed low-N plants. These results, and the chlorosis and accelerated senescence of leaves of sprayed plants, suggested that GA induced a deficiency of N that ultimately became severe enough to injure the photosynthetic mechanism.

If the decrease in E of plants sprayed with GA is caused by acute N deficiency, continuing to supply additional N should prevent or delay its onset and maintain the initial gain in dry-matter production. To test this, potato plants grown in pots with high-N supply, sprayed as previously with 50 p.p.m. GA in aqueous solution 2 or 6 times at weekly intervals, and unsprayed controls, were given additional nitrogen, either as ammonium nitrate applied to the soil or as urea solution sprayed on the leaves twice weekly during the latter part of the growth period; additional P and K was also supplied to all pots. As before, GA at first increased dry weight, but later the increase did not persist even in plants that received the extra sustained N supply. Leaf area was much increased by GA, but E was equally decreased by GA whether or not the additional N was given. The nitrogen contents of the plants have still to be determined, so it is affected leaf nitrogen content, but the results do not support the hypothesis that GA decreases E because it induces nitrogen deficiency. (Humphries and French.)

Leaf-growth substances

The procedure for assaying leaf-growth substances in plant extracts (*Rep. Rothamst. exp. Sta.* for 1958, p. 77) was modified and the red light previously used was replaced by a dim green light, produced by a filter that transmits mainly in the range 500–570 mμ. The difference in growth between disks of etiolated primary leaves of dwarf French bean kept in green light for 15 minutes and disks kept in darkness was only just detectable.

The disks grow less when floated with the abaxial instead of the adaxial surface in contact with the test solution. Similarly, vaseline smeared on the abaxial surface inhibited growth more than on the adaxial surface. As the abaxial surface of primary leaves of dwarf bean has more than seven times as many stomata as the adaxial surface, the solution or vaseline probably decreased growth by blocking the stomata and interfering with gas exchange. In support of this, orientation on the test solution affects the growth of bean-leaf disks much more than disks cut from the first foliage leaves of radish, which have fewer than twice as many stomata on the abaxial surface as on the adaxial surface.

The presence in extracts of cotyledons or primary leaves of dwarf French bean seedlings of an acidic leaf-growth promoting substance that moves on paper chromatograms at the same rate as GA was reported last year (*Rep. Rothamst. exp. Sta.* for 1958, p. 78). The

amounts of this substance in plants grown in a controlled environment at 25° C. were measured. Extracts made from cotyledons and leaves taken at intervals were assayed by the etiolated-bean-leaf-disk test, calibrated with serial dilutions of GA solution. The amount of the growth substance in the cotyledons increased to a maximum after 4 days' growth, whether in light or dark. In plants grown in light the maximum content in the primary leaves occurred later than in the cotyledons, and coincided with the time of maximum growth rate of the primary leaves. In darkness, the primary leaves did not expand and the growth substance did not accumulate in them. The correlation between content of leaf-growth substance and growth rate of the primary leaves suggests that the substance causes leaf growth. No neutral or basic substances that promoted leaf expansion were found in extracts of primary leaves.

The higher sensitivity to GA of disks cut from etiolated primary leaves of plants grown from lighter seeds, reported last year, prompted an examination of the leaf-growth-substance content of seeds of different weight grades, germinated for 1 or 3 days at 25° C. No differences in leaf-growth-substance content were found, but dry weight, leaf area and height were all greater in plants grown from the heavier seeds. The leaf-growth substance in cotyledons of dwarf bean disappeared when the seeds were washed for 24 hours in tap-water, and plants grown from these seeds were smaller than plants from seeds soaked by the standard procedure for only 1 hour before planting. Hence part of the leaf-growth substance that controls the growth of primary leaves may come from the cotyledons. (Wheeler.)

Mode of action of gibberellic acid, kinetin and light on leaf expansion

The method of estimating the number of cells in leaf tissue by digesting it with pectinase and the disodium salt of ethylene-diamine-tetra-acetic acid (EDTA) to separate the cells so that they can be counted (*Rep. Rothamst. exp. Sta.* for 1958, p. 78) was further used to determine whether effects of GA, Kn (kinetin) and light on expansion of disks of etiolated bean leaf are attributable to changes in cell division or in cell extension (5.4).

GA and Kn increased cell size both in light and darkness; light decreased the effect of Kn but greatly increased that of GA. GA increased cell number only in darkness, and had no effect in light, whereas Kn had no effect in the dark but in the light decreased cell division, and this offset the increase in cell size. Consequently, leaf expansion was increased by Kn only in darkness, and GA increased it in the dark but still more in the light. Illumination increased leaf expansion partly by increasing cell number, but mainly by increasing cell size. The interactions of light with externally applied GA and Kn gave no clear evidence that light acts by influencing concentrations of GA or Kn in the leaf. (Humphries and Wheeler.)

Effects of light quality on plant growth

When the controlled environment cabinets were completed, tests were made to find whether fluorescent-tube lighting needs to be supplemented in the red, infra-red region by tungsten incandescent

lamps to give normal growth with the species we use. Kale, sugar beet, barley, tobacco, potato and radish plants were grown in a 16-hour photoperiod at 20° C. under white fluorescent tubes alone, or with varying proportions of additional incandescent light. The light intensity at 2 feet below the fluorescent tubes, measured by a selenium photocell, was 1,450 f.c.; it was not much increased by the incandescent light. However, the total radiation was increased from 6 mW./cm.^{2} with the fluorescent tubes alone to 12 mW./cm.^{2} with the full additional incandescent light.

After 33 days the dry weight of tobacco was increased by additional incandescent light, those of barley, sugar beet and potato were decreased, and those of kale and radish were unchanged. The total leaf area per plant was affected similarly to dry weight, except that the leaf area of sugar beet was unaltered, whereas that of kale was decreased. The incandescent light increased stem extension of potato, kale and tobacco, and decreased shoot number and leaf number of barley.

Similar tests were done with tall and dwarf varieties of garden pea (*Pisum sativum*), broad bean (*Vicia faba*) and French bean (*Phaseolus vulgaris*), and with runner bean (*Phaseolus multiflorus*); in these tests light intensity was also varied. The supplementary incandescent lighting usually increased weight and height, but those of tall pea and tall broad-bean and height of runner bean were unaffected, and weight and height of dwarf broad bean were decreased. Dry weight decreased with lower light intensity, but height was unaffected. Evidently, to obtain optimal growth the form of lighting must be adjusted to the species or even variety of plant.

The area of the primary leaves of the French and runner bean plants was unaffected by the incandescent light or by variation in light intensity. However, the first trifoliate leaves of the French and runner beans were larger on plants that had incandescent light, possibly because increased internode extension under incandescent lighting brought the trifoliate leaves closer to the lights. (Humphries and Wheeler.)

Experiments were done to find whether the increased extension of dwarf-bean stems caused by supplementary incandescent light is associated with changes in growth-substance content. The mean height of dwarf French-bean plants after 12 days' growth in fluorescent light (720 f.c.) was 180 mm.; with additional incandescent light it was 326 mm. Most of this increase occurred in the three internodes above the epicotyl. Extracts of these internodes were separated on chromatograms, and zones corresponding to GA and indolylacetic acid marker spots were assayed by the etiolated-bean-leaf-disk test and the wheat-coleoptile test respectively. The longer internodes of the plants that received additional incandescent light had a higher auxin content than those grown in fluorescent light alone, and their gibberellin content was apparently also higher, but not significantly.

The incandescent light did not affect the area of the primary leaves of 7-day-old plants, nor did it alter the amounts of growth substance in the leaves. This work will be repeated with the larger numbers of plants and higher light intensities possible in the new controlled environment cabinets.

No difference was found between dwarf bean plants grown in darkness and plants grown in light in amounts of auxin or gibberellin-like growth substance in hypocotyls or epicotyls, although the etiolated stems were more than twice as long as those of plants grown in light. (Wheeler.)

Formation of adventitious roots

When hypocotyls of young dwarf French-bean plants, severed a few cm. below the cotyledonary node, are kept with their base in nutrient solution, adventitious roots form on the hypocotyl and sometimes on the epicotyl. This process was greatly stimulated when the hypocotyls were pretreated for some hours with a solution of indolylacetic acid (IAA) or naphthalene acetic acid (NAA) before transfer to the culture solution. Similarly, adventitious roots formed at the cut end of petioles of detached dwarf French bean leaves kept in nutrient solution, and pretreatment with IAA or NAA caused roots to form along the length of the petiole and not only at or near the cut end. Addition of 0·5–1 p.p.m. kinetin (Kn) to the nutrient solution inhibited root growth in untreated hypocotyls or petioles, and greatly restricted it in hypocotyls or petioles pretreated with IAA. Although Kn prevented the differentiation of roots, it did not inhibit cell division; on the contrary, it induced the formation of a white callus 8–10 mm. in diameter at the cut end of the petiole. When the Kn treatment was maintained for several weeks the callus continued to grow, but after Kn was withheld roots began to emerge from the callus tissue. Little or no callus formed at the end of hypocotyls treated with Kn, but more was formed at cut surfaces of epicotyls. Pretreatment with NAA increased the dry weight of hypocotyls. Subsequent Kn treatment also increased the dry weight of untreated hypocotyls by up to 25%, but had no effect after pretreatment with NAA. (Humphries.)

Stimulating cell division and root formation in hypocotyls by treatment with NAA greatly increased total phosphorus content, e.g., from 200 to 500 g. P/hypocotyl, but Kn had no effect on total P content. Orthophosphate, acid-soluble bound P, lipid P, ribonucleic acid P (RNAP) and deoxyribonucleic acid P (DNAP), were all increased by pretreatment with NAA without Kn, but after Kn treatment, when root formation was inhibited, NAA increased only acid-soluble bound P and DNAP. Kn treatment increased acid-soluble bound P, lipid P (in absence of NAA) and DNAP, but decreased orthophosphate P and RNAP, i.e., it had opposite effects on DNAP and RNAP. The results suggest that Kn increased the rate at which orthophosphate was used. The large increase in RNAP caused by pretreatment with NAA may be associated with increased cell number. The total phosphorus content per cent of fresh weight of callus tissue formed on petioles by treatment with Kn was only 50–70% of that of the petiole tissue. (Humphries and Potapczyk.)

Kinetin and indolylacetic acid increased the activities of ribonuclease and deoxyribonuclease in extracts of dwarf French bean hypocotyls; gibberellic acid had no such effect (5.5). (Potapczyk.)

The effect of boron on formation of adventitious roots by severed hypocotyls of dwarf French bean (*Rep. Rothamst. exp. Sta.* for 1957, p. 84) varied with the quality of the light in which the plants

were grown. Hypocotyls from plants grown in light from fluorescent tubes alone, supplied with a nutrient solution without boron, produced about three times the weight of roots as when additional incandescent light was given, whereas when boron was supplied additional incandescent light nearly doubled the weight of roots. (Humphries.)

Phosphorus compounds in plant tumours

Crown-gall tumours produced by inoculating stems of *Datura stramonium* with *Agrobacterium tumefaciens* contain more phosphorus than normal stem tissue. The increase in total P is made up of increases in the amount of acid-soluble P, lipid P, ribonucleic acid P and deoxyribonucleic acid P. The activities of ribonuclease, deoxyribonuclease and glycerophosphatase were all considerably higher in tumours than in normal stems (5.6). These changes are similar to those found in some animal tumours. (Potapczyk.)

Growth Analysis

Effect of soil water deficit on plant growth

In the Irrigation Experiment at Woburn (*Rep. Rothamst. exp. Sta.* for 1955, p. 77), when prolonged drought was broken by a little rain, sugar beet sometimes showed a spurt of growth. When plants on unirrigated plots with a water deficit of 6 inches received less than 1 inch of rain, they temporarily had a higher relative leaf growth rate and net assimilation rate, and for a short period produced more dry matter, than the much larger irrigated plants that had never suffered from water stress. This effect has been reproduced in a sugar-beet crop grown on plots under a Dutch-light structure with the whole water supply under control, after two relatively unsuccessful attempts. (*Rep. Rothamst. exp. Sta.* for 1957, p. 89, 1958, p. 79). Its magnitude probably depends on the size of the plants when subjected to drought, the severity of the water stress and possibly on the prevailing weather.

Sugar-beet seedlings raised in soil blocks were transplanted to the glasshouse in early May, and received uniform watering (4·8 inches) until the beginning of June. The following treatments, similar to those used in 1958, were then applied to different replicated plots:

(a) *Minimal water stress*, maintained by frequent watering.

(b) *Early drought.* The plants were subjected to one drought cycle, compared with three in 1958. No water was given from 2 June until 30 June, when the water content throughout the top 12 inches of soil had fallen to permanent wilting point, and the deficit was $4\frac{1}{2}$ inches; $\frac{1}{2}$ inch of water was then applied, and water was again withheld for a fortnight, during which the deficit increased to $8\frac{1}{2}$ inches. Sufficient water was then applied in the next fortnight to restore the soil-water content to field capacity, and from late July onwards, the plot was watered as for (*a*).

(c) *Late drought.* Water was supplied as for (*a*) until 25 June, and then no more was given.

The total amounts of water applied from the beginning of June to mid-September were: (*a*) 17·4 inches; (*b*) 14·0 inches; (*c*) 3·5 inches.

By the end of June, plants receiving treatment (*b*) had only half as much leaf area and two-thirds as much dry weight as the fully watered plants. In the period immediately after applying ½ inch of water at the beginning of July, their net assimilation rate and relative leaf-growth rate increased to about double those of the fully watered plants, and this difference persisted during the next 14-day period while the soil water content returned to field capacity. The dry-matter increment during July was slightly, though not significantly, greater for treatment (*b*) than for the others. These results closely parallel those found in the field at Woburn in 1955. By the end of August dry-weight yield and leaf-area index were the same for treatments (*a*) and (*b*).

Treatment (*c*) had no detectable effect until early August, when the plants had less area and weight of leaves than those of treatment (*a*). At the final harvest in late September treatment (*c*) had decreased the total dry matter yield by only 9%, and its effect was nearly all on the leaves; the small difference in root dry weight between treatments (*a*) and (*c*) was not significant. This result suggests that, provided the sugar-beet crop has a full water supply during its establishment and early growth, irrigation in the later stages of growth is unlikely to be effective.

Drought and subsequent watering affected leaf area per plant mainly by affecting leaf expansion. After the plots of treatment (*b*) were brought back to field capacity in July the plants for a short time had more leaves than those on other plots, and at the end of the growth period there were fewer leaves per plant with treatment (*c*) than with treatment (*a*) or (*b*), but these differences in leaf number were small compared with those in leaf size.

Although there was much more sunshine in 1959 than in 1958, the dry weight yield was nearly the same in both years; a higher mean net assimilation rate in 1959 was offset by a lower leaf-area index. (Orchard.)

Measurement of leaf area

The scanning planimeter (*Rep. Rothamst. exp. Sta.* for 1958, p. 81) was used for routine leaf-area measurements for a full season. It proved reliable, as well as being quick and easy to operate, and gives results comparable to those obtained by more laborious methods. A planimeter based on the same principle, but adapted to measure areas of long, narrow leaves, like those of cereals and grasses, is being designed. (Orchard.)

Varietal differences in yield of barley and wheat

Previous work suggested that Proctor and Herta barleys give higher grain yields than the older variety Plumage Archer because their ears photosynthesise more. The greater photosynthesis by ears of Proctor and Herta cannot be attributed to relatively greater amounts of ear tissue; on the contrary, a pot experiment in 1958 showed that the ear : shoot dry-weight ratio at ear emergence was smaller for Proctor and Herta than for Plumage Archer, although

this difference was subsequently reversed by greater growth of the grains of Proctor and Herta (*Rep. Rothamst. exp. Sta.* for 1958, p. 82). The experiment was repeated with Proctor and Plumage Archer in 1959, but some ears were covered with opaque paper shades to prevent them photosynthesising, and samples of shaded and unshaded ears were taken at intervals between ear emergence and maturity. As before, the ear : shoot dry-weight ratio of Proctor was less at emergence and greater at maturity than that of Plumage Archer, but this was true for shaded as well as unshaded ears, showing that the reversal cannot be attributed solely to a difference between varieties in amount of photosynthesis by the ears.

Shaded and unshaded ears of Proctor both grew faster than those of Plumage Archer, and this was associated with a slightly greater loss in dry weight between ear emergence and maturity from shoots of Proctor than of Plumage Archer. Proctor ears may grow more rapidly because translocation from the shoots is greater. Leaves of Proctor survived longer than those of Plumage Archer, so that leaf-area duration between emergence and maturity was greater for Proctor, though not enough to account for the greater increase in ear dry weight. In this experiment, therefore, leaves of Proctor appeared to be more efficient in dry-matter production after ear emergence than those of Plumage Archer; no evidence of this was found previously. The experiment was unsatisfactory because the size and yield of grains and the effects of shading ears were all much smaller than usual, probably because the plants ripened prematurely in the exceptionally high glasshouse temperatures. Another variety, Brant, a Canadian six-rowed barley adapted to a short, hot growing season, was included in the experiment and was not adversely affected, but yielded as well as in previous pot experiments in Canada. Shading ears of Brant decreased their dry weight by 30%; this is more than for two-rowed barleys, presumably because the six-rowed ears are larger and so photosynthesise more, relative to leaves and stems.

Photosynthesis by ears during the period 4–5 weeks after emergence was measured directly with an infra-red gas analyser. In 18 comparisons between shoots cut from adjacent field plots of Proctor and Plumage Archer, apparent photosynthesis per ear did not differ significantly between varieties. Respiration rate per unit dry weight, measured at night, was similar for the two varieties, so respiration rate per ear was greater for the heavier ears of Plumage Archer. Consequently, true photosynthesis per ear was greater for Proctor. Apparent photosynthesis per unit surface area of ear, also, was greater for Proctor because it has smaller ears than Plumage Archer; the mean total assimilating surface of Proctor ears, including awns, was about 70% of that of the Plumage Archer ears. This confirms the conclusion reached previously for other reasons that Proctor ears have a higher net photosynthetic efficiency than Plumage Archer ears, and implies that the contribution to total grain yield made by photosynthesis in the ear is greater for Proctor because it produces more, though smaller, ears than Plumage Archer.

No differences in total shoot dry weight or in ear : shoot ratio were found between the spring wheats Fylgia I and Koga II,

although in the field Koga II has shorter straw and higher grain yield than Fylgia I. Comparisons between shaded and unshaded ears showed that in both varieties photosynthesis in the ears contributed about 20% of their dry weight. (Thorne.)

The nature and effects of competition within a crop

As is well known to exhibitors at agricultural shows, plants in a field crop are smaller than they would be if grown in isolation, because they compete with each other for factors that influence their growth. Increase in density of plant populations produces smaller individual plants, so that final yield per acre is nearly independent of variation in plant number over a wide range. Conversely, in thin patches of a crop, or at the edges where the plants are without neighbours on one side, the plants grow larger; " edge-effects " are often obvious in field experiments where the plots are separated by paths.

An experiment on competition in winter wheat sought the stage when competition becomes effective, what changes it induces in the plants and what environmental factors are involved in the competition. Plots were arranged with 9 rows spaced at the normal 7 inches, separated by single rows with 21-inch spacing; one set of plots was drilled with rows running east to west, and another with rows running north to south, to find whether growth of edge-rows was affected by differences in exposure to sunlight. Growth measurements were made throughout the season, and the results await analysis by the electronic computer. (French, Watson and Witts.)

Photosynthesis of leaves at different levels in a crop

A previous experiment, which measured the effects of removing increasing proportions of the foliage of plants in a kale crop on the dry weight increment in the following fortnight (*Rep. Rothamst. exp. Sta.* for 1957, p. 91) showed that the upper, younger leaves were much more effective in dry-matter production than the lower leaves. The four uppermost leaves out of an average of 11 per plant, together representing 30% of the total leaf area, produced 66% of the total dry-weight increment, and their net assimilation rate (E) was five times that of the four lowest leaves. If the vertical gradient in photosynthetic efficiency resulted from shading of the lower leaves, the difference between upper and lower leaves should be less when leaf area index (L) is smaller, and this was tested by removing alternate plants from some plots so as to halve L. The experiment was not precise enough to detect differences in effects of defoliation between thinned and unthinned plots, but the results suggested that decreasing L had similar effects on E of leaves at all levels, i.e., it did not much affect the gradient in E.

The experiment was therefore repeated with more replicates and a design expected to give more accurate estimates of dry-matter increment. Unfortunately, the results show some unexplained anomalies, but again the vertical gradient was no less on the plots with the smaller L.

E of sugar beet depends less on L than does E of kale, possibly because the morphology of the sugar-beet plant ensures more uniform illumination of the whole foliage with less severe shading of

the lower leaves than in kale. If this is correct, differences in E between upper and lower leaves should be smaller in sugar beet than in kale. However, an experiment similar to those on kale, but without the thinning treatment to vary L, showed gradients in E very like those found for kale; the 8 youngest leaves of sugar-beet plants with a mean of 23 leaves, representing 19% of the total leaf area, contributed 53% of the dry-matter increment, and E of these young leaves was about six times that of the 8 oldest leaves.

These results suggested that the gradient in E between the upper, young leaves and the lower, old leaves might reflect differences in age rather than in illumination, but direct measurements with an infra-red gas analyser made on detached leaves showed no consistent differences in rate of photosynthesis between leaves of different ages. (French, Thorne, Watson and Witts.)

Weed Studies

Wild oats

Survival of seeds under temporary ley. The decline in numbers of seeds of *Avena fatua* able to germinate after an increasing period under temporary ley in the experiment at Rothamsted (*Rep. Rothamst. exp. Sta.* for 1956, p. 80, 1957, p. 92, and 1958, p. 83) continued in 1959; on plots ploughed in Autumn 1958 after 4 years under grass only 0·6 seedlings/sq. yd. appeared, compared with 1·2/sq. yd. in 1958 on plots ploughed after 3 years. Although the decrease from 28·5 per sq. yd. at the beginning of the experiment to 0·6 per sq. yd. after 4 years under ley is big enough to be agriculturally useful, there are still about 2,500 viable seeds per acre, and ploughing up and cropping at this stage without control measures against wild oats would soon restore the original infestation. In this experiment, each ploughed-up plot is reploughed at the end of its first year and kept under observation for a further year. The seedlings found in the second season have remained nearly constant at about 1/sq. yd. for 1, 2 and 3 years under grass, suggesting that there may be a residue of heavily-dormant seeds that retain their viability longer than those that are easily induced to germinate.

Soil samples taken in spring from the field in Northamptonshire that has a mixed infestation of *A. fatua* and *A. ludoviciana* and has been under ley for 5½ years showed no significant decrease in numbers of apparently viable seeds since the previous year. The field still has nearly 5 million seeds/acre, and the number is not decreasing, unlike the lighter infestation at Rothamsted. To check that the seeds counted after recovery by washing on sieves are viable, germination tests on another set of soil samples are in progress in the glasshouse.

Wild oats from other countries. The germination behaviour of seeds of *A. sterilis* from Algeria, Malta, Greece and Arabia was studied. As with *A. ludoviciana*, the second and subsequent seeds of a spikelet were progressively more dormant and tended to germinate later than the first seed. Some seeds of Algerian *A. sterilis* took 4 years to germinate in pans in the glasshouse. The only British wild oats to stay dormant so long in these conditions were two selections of *A. ludoviciana*, type 1D (probably var. *typica* sub. var. *hibernans* Malzew).

A. barbata from Malta had a germination pattern similar to that of *A. sterilis* and *A. ludoviciana*, with 50% non-dormant seeds, and no germination between February and August. In this species the successive seeds, like those of *A. fatua*, are not distinguishable, as they are shed separately and each has an abscission scar.

As arranged at the meeting of the International Research Group for Weed Control at Stuttgart, samples of wild oats seeds were received for identification; 289 samples came from seven European countries. *A. fatua* predominated, and came from all countries. *A. ludoviciana* was only in samples from central and southern France, and the one sample of *A. barbata* came from the south of France. No other species were present. Different types of *A. fatua* vary in their geographical distribution; a sort with grey glabrous seeds and short hairs at the callus was characteristic of Scandinavia, and also occurred in samples from Holland but only rarely from Belgium, France or Germany; the type commonest in Britain, fA, was also abundant in France, Holland and Belgium but infrequent in Scandinavia. There is an odd discontinuity in the distribution of *A. ludoviciana*; it occurs in England and the southern half of France, but not in northern France. This may be because it is a recent chance introduction into England (it is thought to have arrived here in French wheat imported during the 1914–18 War) or because the winters in England are milder than in northern France.

Effect of gibberellic acid on germination. As gibberellic acid increases germination of seeds of some other species, its effect was tested on seeds of *A. ludoviciana*. First seeds of the spikelets were soaked for 24 hours at room temperature either in tap-water, with or without subsequent pricking of the seed coats with a needle, or in gibberellic acid solution (50 p.p.m.) and then put to germinate in incubators at different temperatures. At 7° C. 95% or more of the seeds germinated irrespective of treatment, but at higher temperatures more pricked than unpricked seeds germinated, and gibberellic acid treatment was nearly as effective as pricking in breaking temperature-induced dormancy, e.g., at 27° C. only 10% of unpricked seeds germinated, but pricking or treatment with gibberellic acid gave 50% germination. Gibberellic acid solution was less effective when the seeds were soaked in it for less than 20 hours; 25 p.p.m. were as effective as 50 p.p.m., but lower concentrations had less effect. (Thurston.)

Other weed species

A test set up 3 years ago has shown that seeds of corn marigold (*Chrysanthemum segetum*) germinate mainly in the period August to March, and not during the summer; 93% of seeds have now germinated, and a few seedlings continue to appear.

Seedlings of fat hen (*Chenopodium album*) and orache (*Atriplex patula*) are easily confused, but observations on seeds germinated in the glasshouse show that they can be distinguished by the colour of the backs of the cotyledons at emergence—mauve in *C. album* and green in *A. patula*. Seeds of *A. patula* germinated only in April and May, but *C. album* germinated throughout the summer until August,

though most seedlings appeared in spring. Only 40% of seeds of *A. patula* and 65% of *C. album* germinated in the first year. (Thurston.)

Weeds of Broadbalk

At the suggestion of F. T. Last (Insecticides and Fungicides Department), the records of occurrence of the semi-parasitic plant *Bartsia odontites* on Broadbalk were examined to compare with his observations on *Striga* attacking sorghum in the Sudan. Like *Striga, Bartsia* was less abundant on plots that receive nitrogenous fertiliser than where no nitrogen is given, probably because of increased competition from the crop rather than any direct effect of nitrogenous fertiliser on germination or establishment of *Bartsia* seedlings. *Bartsia* was slightly more abundant in the first wheat crop after fallow than in subsequent crops, and this suggests that germination may be stimulated by presence of the crop, but the crop is not essential because *Bartsia* seeds will germinate in isolation on filter-paper or in soil.

Soil samples were again taken from Section 1a of Broadbalk, which has reverted to continuous wheat with weed control by herbicidal sprays, and Section 1b, which continues in the fallow cycle without herbicides, to measure changes in the weed-seed population. Although the counts are not yet complete, three successive years of herbicide treatment have clearly lowered the numbers of dicotyledonous weed-seeds, but some species, including *Alchemilla arvensis*, *Papaver* spp. and *Veronica arvensis*, are still more abundant on Section 1a than on 1b. (Thurston.)

Competition between crop and weeds

Weed density and crop yield. Experiments were started to measure the losses of crop yield caused by different weed species and how they depend on the density of the weed population. Such information may make it possible to apply control measures more rationally, by deciding from knowledge of the nature and density of an infestation whether or not the increase of crop yield to be expected from eradicating the weeds would justify the cost.

In the first experiment on two fields of spring wheat, 90 small plots were selected so that their weed floras represented a wide range of densities of common weeds; the species present included *Atriplex patula* (orache), *Chenopodium album* (fat hen), *Polygonum convolvulus* (black bindweed), *P. aviculare* (knotgrass) and *Stellaria media* (chickweed). Another 20 plots were selected in a field of winter wheat infested with *Sinapis arvensis* (charlock), *Papaver rhoeas* (poppy) and *Ranunculus repens* (creeping buttercup). Each plot was halved, and one half chosen at random was covered with polyethylene sheet to protect it from herbicide when the whole field was sprayed. The uncovered, sprayed, half-plots acted as controls for the covered halves and the difference in crop yield between them measured the effect of the weed controlled by the spray.

The density of each of the common weed species on each plot was estimated by inspection at the time of spraying, and on about half the covered plots the seedlings were counted on sample areas, so that the density ratings could be calibrated in terms of plant

numbers. The crop on each plot was cut by hand just before the field was fit for combining, threshed and the weights of grain and straw determined. Partial regressions of decrease in yield on the density of each species are being calculated on the electronic computer, but inspection of the data suggests that the effects of the weeds may be small, possibly because of the unusually dry season. (Welbank.)

Survey of competitive effects of common weed species

The series of experiments to compare the effects of common annual weeds on the growth of crop plants (*Rep. Rothamst. exp. Sta.* for 1958, p. 86) was continued. Single plants of kale or wheat were grown in pots alone or with *Chenopodium album*, *Polygonum aviculare*, *P. persicaria* or *Atriplex patula*. There were 16 weed plants per pot, except with *Atriplex*, which germinated poorly, and pots were also planted with weeds alone. Two rates of nitrogen supply were tested. The above-ground parts were harvested after 8 weeks; the roots of crop and weeds could not be separated.

Chenopodium and the two *Polygonum* species affected crop plants similarly, but *Atriplex* had less effect, probably because of its lower density per pot. With low N supply, the weeds decreased leaf area and dry weight of both kale and wheat by about 40%. With high N supply all weeds had slightly less effect on kale than with low N supply, but had a much greater effect on wheat, decreasing leaf area and weight by 60%. Weeds usually affected stems less than leaves, except that with high N supply *Chenopodium* decreased stem dry weight of wheat more than leaf weight, so that in presence of *Chenopodium* the weight of wheat stems was less with high N than with low N supply. Competition with kale decreased the weights of weeds more than competition with wheat, and the effects of crop on weeds were similar at both rates of N supply.

The results suggest that, for kale, competition with weeds for nitrogen was important, but for wheat it was subsidiary to some other factor. Why *Chenopodium* behaved differently from the *Polygonum* species in its effect on wheat stems is not clear. The difference was associated with lower shoot number and leaf nitrogen content in wheat plants grown with *Chenopodium*. Shading may have been greater with *Chenopodium* than with the other weeds, and this may have decreased the capacity of the wheat plants to assimilate nitrogen. (Welbank.)

Competitive effects of Agropyron repens (*couch grass*)

The results of an experiment done in 1958 to find whether the harmful effects of *Agropyron repens* on crops can be explained by competition for nutrients in the soil (*Rep. Rothamst. exp. Sta.* for 1958, p. 87) were analysed. Young sugar beet transplanted singly into pots in which *Agropyron* was already growing, or into similar pots without *Agropyron*, received all combinations of three rates of nitrogen application and three rates of potash. Pots of *Agropyron* without sugar beet were set up with the same treatments to measure the effects of nutrient supply on the grass. The plants were harvested after 2 weeks, fresh and dry weights and leaf areas were

recorded, and the dried plant materials were analysed for N, P and K.

The relative growth rate of the sugar beet was increased by N and K treatment and decreased by competition with *Agropyron*. The mean response to N, but not to K, was greater with competition than without. Similarly, the effects of N on relative leaf growth rate and on percentage dry matter of leaves, stems and roots were all increased by competition, but those of K were not. Thus the yield data alone indicate that there was competition between sugar beet and *Agropyron* for N but not for K.

However, competition with *Agropyron* decreased uptake of both N and K by sugar beet; the effect on N uptake was the greater, and the decreases in both N and K were largest at the lowest rates of nutrient supply. All the effects of treatments on growth, including those of competition, could be related to differences in N and K uptake rates. Apparently competition was acting solely through its effects on these rates, with competition for N having more effect than competition for K. There was evidence, however, that competition may decrease uptake of a given nutrient in other ways than by diminishing the amount of it in the soil, e.g., by depleting another nutrient that interacts with it. (Welbank.)

Production of toxic substances by Agropyron repens

Previous work gave no support to the suggestion that the harmful effects of *Agropyron repens* on crops is partly caused by toxic substances secreted by the living roots or rhizomes (*Rep. Rothamst. exp. Sta.* for 1958, p. 87). The possibility that toxin production occurs during decay of *Agropyron* residues in the soil has now been tested.

Fresh roots and rhizomes were cut up and mixed with 40 parts by weight of Woburn soil to 1 part of dry weight of plant material. Water was added in varying amounts to give differences in oxygenation and the mixtures were incubated at 20° C. Soil alone was used as control. After 15 and 22 days the mixtures were extracted with water, making a total of 50 ml./g. of dried plant material, and the extracts clarified and sterilised by filtration and the pH adjusted to 5·8. Toxicity was tested by placing germinated rape seed in the extracts, and measuring radicle and hypocotyl lengths after 3 days. Germination tests also were done with rape.

Incubation with poor oxygenation (high water content) produced extracts highly inhibitory to extension growth of rape; radicle elongation was approximately halved by extracts of root preparations, and decreased to about one-third by rhizome preparations; hypocotyls were less affected. After 22 days' incubation, extracts were more toxic than after 15 days. One of the most potent rhizome-extracts lost its effect when diluted 16 times. Germination tests gave variable results, though many extracts were obviously inhibitory.

To check that toxicity was not caused by some soil mineral such as manganese dissolving at the low pH of many of the plant–soil mixtures, plant material was incubated with only a small inoculum of soil. It gave an extract nearly as toxic as when the large amount of soil was used. However, soil alone incubated with citrate buffer

at pH 5·1 was also slightly toxic, so it is still not clear whether acidity is responsible for the effect.

Extracts from preparations with better oxygenation (lower water content) during incubation had little or no effect on seedling growth.

Field observations suggest that the amounts of root and rhizomes present in land heavily infested with *Agropyron* are enough to affect crop growth by toxin production when they decay in suitable conditions, but there is no reason to suppose that this effect is specific to *Agropyron*, for other workers have found that extracts of other plant residues incubated with soil inhibit germination and respiration of tobacco. (Welbank.)

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

R. J. Stephens resigned and the vacancy was filled by G. Jenkins; the temporary vacancy during the secondment of R. H. Kenten to the West African Cocoa Research Institute (Tafo, Ghana) was filled by N. Singh; both the appointments made possible by the Rockefeller Foundation grant have now been filled, the second by N. G. Davys. Miss C. Morton and Mrs. W. Duah came for about a month to give us expert help in cooking leaf protein.

At the invitation of the Government of Ghana, Marjorie Byers spent three months in Kumasi studying the extractability of protein from the types of leaf available there; as guest of the Bulgarian Government, N. W. Pirie visited agricultural institutes in Bulgaria.

The Extraction of Protein from Leaves

Laboratory scale investigation

The domestic mincer and three-roll ointment mill have been used during the past 20 years to study the extraction of protein from leaves readily available at Rothamsted; this year the study was extended to leaves common in Ghana. The 60 species examined ranged from specially grown crops, through leaves that are a by-product of some other crop (e.g., sweet potato and sugar cane), to wild plants. Eight species yielded high-quality protein and about half the protein of the leaf was extractable; as would be expected, these were mainly legumes with soft leaves. This was a hurried preliminary examination, but it showed that tropical plants have leaves suitable for large-scale extraction of protein and that the texture and appearance of a leaf are fairly reliable guides to its value. (Byers.)

In the hope of getting more reproducible conditions of disintegration, a unit was made in which leaves were forced through a narrow annular slot at pressures up to 10 tons/sq. in. Disintegrating tobacco leaves at different stages of growth in this unit has given some information about the factors that affect the extractability of leaf protein. Slightly alkaline conditions increase the extraction, mainly because of increased breakdown of the chloroplasts so that their fragments separate more fully from the fibre. Protein extraction is not more complete by this method than it is in high-speed grinders of the " Waring Blendor " type, but a larger proportion of what is extracted remains suspended after centrifuging at 1,500 g. It is not yet clear whether the difference arises because one method is breaking up structures originally present in the leaf, or the other causes some protein to coagulate. Much of the protein that remains in the fibre fraction after these processes is liberated by extraction with detergent solutions, and the state of subdivision of the protein in the initial extract is increased by addition of detergents. This may be important in increasing the yield of protein in large-scale extraction. (Festenstein.)

Extracts made for the large-scale production of leaf protein were also fractionated centrifugally in the laboratory to see whether the losses, when extraction is inadequate, are evenly distributed among all the protein fractions or fall characteristically on one of them. In comparisons between samples of the same crop at different stages of maturity the losses are evenly distributed, but the position is less clear when different species are compared.

For 185 years it has been known that the proteins in leaf extracts precipitate in sequence as the extracts are increasingly heated and that those associated with chlorophyll coagulate first. This is rediscovered from time to time, and it is often suggested that the fact might be applied to make colourless bulk preparations. Several lots of leaf sap from seven different species were examined and, by judicious heating, 30% of the protein extracted from mustard and pea leaves was obtained in a relatively colourless fraction; the process was less satisfactory with other species. (Singh.)

Large-scale preparations

In spring bulk production for a pig-feeding experiment at the Rowett Research Institute took precedence over other work. This was essentially a repetition of last year's experiment at the National Institute for Research in Dairying; both showed that leaf protein is as good as or a little better than fish meal.

Two new crops, *Chenopodium amaranticolor* and turnip tops (*Brassica rapa*), were added to the list of species processed on a large scale. The cereal crops used were confined to wheat, rye and maize. This year the weather was again atypical, with the hot, dry summer a striking contrast to 1958. A good maize crop was grown in these conditions under irrigation, in contrast to the complete failure last year; but the lack of rain affected many of the crops grown for use in July and August. In particular, white clover failed to grow tall enough to be cut mechanically. (Byers and Jenkins.)

A new press was built to our design and works satisfactorily. Leaf pulp is carried on a perforated annulus under a platen with a thick rubber face; the platen is hinged at one side and is lifted and pressed down by cams; during the lifting movement, the platen engages a lever system that moves the annulus round so as to bring a new lot of pulp into position to be pressed. The press is much simpler than the older one, but, like it, is in effect continuous, although pressure is maintained for periods that can be varied from 4 to 15 seconds so as to allow the juice to run away completely.

The unit designed to extract leaf sap in one operation from 100–300-lb. lots of leaves progresses, but we are still not satisfied that we have a satisfactory design to offer to an institute or village wishing to start production in a small way. (Davys and Pirie.)

The techniques of handling leaf extracts to make the standard type of protein remains essentially unchanged, but we have improved the technique of drying the protein so as to get a stable product. Air-dried protein is rather dark and gritty, and freeze-dried protein is not much better when the moist material is frozen slowly in a deep-freeze before being put in the vacuum chamber. When unfrozen protein is used, in lots small enough to freeze within

a few seconds *in vacuo*, the dried material is pale and soft textured. Four or five pounds of dry protein can be made in a week with our equipment.

Fresh, moist protein was mostly used in cooking, and an extensive repertoire of recipes was devised. Some cooked foods keep well and can be given to visitors to eat at any time, others can be produced from stored pre-mixed ingredients in a few minutes, but some need longer preparation. Tastes vary, but every visitor found at least one of our dishes acceptable. (Morrison and Pirie.)

Studies on Plant Enzyme Systems

Plant-leaf mitochondria

Evidence that mitochondria isolated from tobacco leaves retain much of their structural and chemical organisation came from two sources. First, they catalyse the process of oxidative phosphorylation, which depends on the closely integrated action of a series of enzymes and co-enzymes; secondly, they retain the "soluble" enzyme fumarase, which is released from them by treatments which rupture the external mitochondrial membranes. This chemical evidence for mitochondrial organisation is supported by the appearance of the isolated mitochondria in electron micrographs.

Orthophosphate disappears during the oxidation of many substrates of the tricarboxylic acid cycle. This suggests that there is oxidative phosphorylation, and the suggestion was confirmed when chromatographic and radioactive techniques demonstrated the synthesis of adenosine triphosphate (ATP) from orthophosphate. The phosphorylation reactions are only loosely coupled to the oxidations, and are inhibited by treatments such as "ageing" at 37°, or exposure to 2 : 4-dinitrophenol, which have little effect on the oxygen uptake. The amount of ATP formed depends on the substrate being oxidised. With malate and *iso*citrate about 2 atoms of orthophosphates are esterified per atom of oxygen absorbed, values approximately $\frac{2}{3}$ of the generally accepted theoretical maxima.

The fumarase of tobacco leaves is an –SH dependent enzyme which is competitively inhibited by orthophosphate. Over 90% of the total activity of the leaf extracts is in the washed mitochondrial preparations, but treatments as gentle as repeated freezing and thawing disrupt the mitochondria and release about $\frac{2}{3}$ of the activity in a condition not sedimented by high centrifugal forces (50,000 g. for $2\frac{1}{2}$ hours). Thus, although the link holding most of the fumarase on to the mitochondrial preparation is fairly weak, it successfully withstands the isolation procedure.

How far the cytochrome-linked oxidations of the mitochondrial preparations from tobacco leaves account for the oxygen uptake of intact leaves is a matter for speculation. Recent reports implicated glycollic acid oxidation in the respiration of illuminated leaves, and drew attention to the oxidation of glycollic acid by the tobacco-leaf mitochondrial preparations. This oxidation differs from the oxidation of tricarboxylic acids in a number of respects. It is, for example, not inhibited by cyanide, and it is not coupled to the synthesis of ATP. Moreover, most of this activity in the leaf extracts is not associated with any particles sedimented by high centrifugal

forces (55,000 g. for 2 hours); less than one-tenth of the total is associated with the mitochondrial preparations. It seems certain that the oxidation is catalysed by glycollic oxidase and not by a cytochrome system. If any portion of the respiration of intact plants is mediated by this enzyme, it will differ from that catalysed by the cytochromes in not being connected to the " high-energy phosphate " synthesising machinery of the mitochondria. (Pierpoint.)

Enzymic degradation of chlorophyll

Chlorophyllase, the enzyme that splits chlorophyll into phytol and chlorophyllide, has hitherto not been separated from cell fragments and so has been studied in suspension rather than in solution. Soluble enzyme preparations were made this year from acetone-powders of the leaves of several species by soaking in sodium citrate solution for 24–48 hours, after the powder was first extracted with ethanol and ether. For unknown reasons, the citrate extract appears to have several times as much enzyme activity as the powder from which it was derived. Sugar-beet leaves have exceptionally high activity and are by far the most useful source of the enzyme. When the activity of a soluble enzyme preparation is being determined, the acetone concentration has to be brought from 60 to 40%, as the higher concentration is strongly inhibitory, whereas it is optimum for insoluble preparations. The enzyme in solution is fairly stable in the cold at pH values between 7 and 9; a variable amount of activity is lost on dialysis. Attempts to concentrate and purify it have so far failed; even precipitation with ammonium sulphate causes a large loss of activity.

The changes in chlorophyllase levels were followed in different parts of pea seedlings grown on moist sand in full light or in the dark. The enzyme level in the cotyledons rose for the first 5 days and then fell. In the seedlings grown in the light, chlorophyllase activity in the shoot increased rapidly. Roots were almost devoid of activity at all stages. When the seedlings were about 2 weeks old over 80% of the total activity was in the leaves, compared with only about 15% of the dry weight. The stems had most of the rest of the activity. In etiolated seedlings the activity in the shoot increased only slightly while they were in the dark, but the level rose sharply when they were transferred to the light.

Attempts to separate the chlorophyllides by paper chromatography using many solvent systems failed. However, several of these systems separated other breakdown products of the chlorophylls, such as phaeophytins and phaeophorbides, satisfactorily. Attempts are being made to separate these compounds on a larger scale on sugar columns. No trace of coloured breakdown products of chlorophylls were detected in extracts of leaves of mature tobacco plants kept in the dark until they were yellow.

It was confirmed that the leaves of barley seedlings have no detectable chlorophyllase activity but that during incubation in aqueous acetone green oxidation products are formed by enzyme action. No enzyme system was found that converts the chlorophylls and their coloured degradation products to colourless compounds. (Holden.)

Plant amine oxidase—a metalloprotein enzyme

By fractionation on calcium phosphate and aminoethyl cellulose, amine oxidase preparations from pea seedling extracts were purified 1,000-fold. At this stage the enzyme solution is pink, with an absorption band with its maximum at 495 mμ, it is decolorised by dithionite, and the colour is restored by bubbling with oxygen. Carbonyl reagents, such as hydroxylamine, hydrazine, semicarbazide and *iso*nicotinoyl hydrazide, which are known to inhibit the enzyme, also discharge the pink colour. A similar effect of substrate (putrescine), under anaerobic conditions, had previously been reported. These findings suggest that the pink colour is a property of the enzyme.

The presence of copper and manganese in the 300-fold purified preparations was reported in 1954. During the final stages of the purification the copper content increases while the manganese content remains constant or decreases slightly. In highly purified preparations the copper and manganese contents vary from 0·05 to 0·07%. Spectrographic analysis of one preparation (by H. H. Le Riche) confirms that copper and manganese are present in higher concentrations than other heavy metals. The increase in the copper content during purification suggests that the enzyme is a copper protein, as also does its inhibition by agents that chelate copper. Though the manganese content does not increase during purification, it is present finally at the same molar concentration as copper. Manganic manganese forms pink complexes with certain peptides. The light absorption of these manganic peptides closely resembles that of the enzyme preparations, suggesting that the pink colour of the enzyme preparations may be caused by a complex of manganic manganese. Should this prove to be so, the question will arise whether the inhibition of the enzyme by carbonyl reagents, attributed by others to the presence of pyridoxal phosphate in the enzyme, results from the known reactions of these compounds with manganic manganese. (Mann.)

Complexes of manganic manganese with peptides

Manganic manganese is responsible for a pink complex formed when reaction mixtures containing a manganous salt and L-leucylglycine are incubated under alkaline conditions, because it is not formed under anaerobic conditions and manometric experiments show that the intensity of the colour is proportional to the uptake of oxygen. The absorption spectrum of the complex shows a band in the visible region resembling that of manganipyrophosphate but with a maximum at a slightly longer wavelength (495 mμ). The colour is discharged by reducing agents such as dithionite. The complex also oxidises hydrazine with evolution of nitrogen and, as with manganipyrophosphate, this reaction can be used to estimate the manganic manganese of the complex manometrically. Preliminary investigations suggest that some other peptides form complexes with manganic manganese. Positive results were obtained with DL-leucylglycine, glycylglycine and glycyl-DL-alanine and negative results with glycyl-L-leucine. Complexes of manganic manganese probably occur in plants. (Mann.)

Catalysis of the formation of oxygenated cobalt complexes by peroxidase systems

The oxidation of manganous manganese by hydrogen peroxide is catalysed by peroxidase and certain phenols, and this system also catalyses the formation of reversibly oxygenated complexes of cobalt. When peroxidase is added to reaction mixtures containing a cobaltous salt, histidine, hydrogen peroxide and trace amounts of *p*-cresol, a strong yellow-brown colour forms almost instantaneously. The absorption spectrum of the yellow-brown product shows a band with a maximum at 385 mμ. The colour is partially discharged when the reaction mixture is evacuated in a Thunberg tube, and more completely by acidifying; manometric experiments show that the loss of colour is accompanied by evolution of oxygen. The yellow-brown compound slowly changes to a red irreversibly oxygenated complex. These properties are similar to those previously reported by other workers for the reversibly oxygenated oxy-bis (cobaltodihistidine) complex. (Mann.)

Autolytic enzymes

More nitrogen is always precipitated from a leaf extract by trichloro-acetic acid than by boiling the extract; the difference is sometimes as great as 15%. This has long been known, but the phenomenon remained unexplained. It is now clear that ribonuclease and leaf protease are responsible. Nucleic acid is precipitated by trichloroacetic acid along with protein, but accompanies the protein into the precipitate only when it is intact, and exposure to the ribonuclease in most leaf extracts destroys it. Therefore, when the extract is allowed to age before precipitation there is less intact nucleic acid and, ribonuclease being a relatively thermostable enzyme, nucleic acid is also destroyed during the heating that precedes boiling. This can be demonstrated by determining the nucleic acid in protein precipitates made by both methods after varying amounts of heating and incubation. The protease activity of leaves that do not contain latex is small but not negligible. For example, 40% of the protein in the sap of young wheat becomes unprecipitable by either heat or trichloroacetic acid when the sap is incubated for 2 hours at 37° before precipitation. The effect is less with the sap of the other leaves yet studied, but these two phenomena suffice to account for the observed differences. (Singh.)

Eelworm Hatching Factors

During 1959 only 2·5 tons of potato-root diffusate (supplied by the Nematology Department) were put through the same preliminary stages of purification as last year. By fractionation on silica columns and precipitation from ether : petroleum ether, the melting point of the cream-coloured, microcrystalline, active fraction was raised to 147–149°, but 70–90% of the material is lost in the process, so that the final yield is 50–250 μg. from a litre of diffusate.

The Nematology Department also supplied ⅓ ton of tomato-root diffusate, which, like potato-root diffusate, stimulates eggs of *Heterodera rostochiensis* to hatch. The active material in both diffusates

seems to be the same, and the purification procedure developed with potato-root diffusate yielded a similar active product from tomato-root diffusate. Furthermore, with six different solvent systems, both products show maximum hatching activity at similar regions of paper chromatograms.

Work was started on the root diffusates from rape, which contains hatching factors for the cabbage-root eelworm (*Heterodera cruciferae*) and the beet-root eelworm (*Heterodera schachtii*).

More bioassays are needed before the results can be assessed properly, but the procedure for isolating the hatching factor from potato-root diffusate gave an end product that stimulated eggs of beet-root eelworm to hatch. The product resembles the potato hatching factor in its solubility properties, fluorescence and chromotographic behaviour, but does not stimulate hatching of eggs of potato-root eelworm. (Clarke.)

PLANT PATHOLOGY DEPARTMENT

P. H. Gregory

T. Mulligan left to become virologist at The Albert Agricultural College, Glasnevin, Dublin, and was succeeded by R. C. Sinha; A. J. Gibbs was appointed to replace L. Broadbent. The following joined us as temporary workers: H. Dias (Lisbon), J. Gourlet (Paris), Katri Ikaheimo (Helsinki), J. Lacey (Reading), M. A. Ram Reddy (Hyderabad), R. D. Tinline (Saskatoon).

A. Kleczkowski contributed to the Conference on Inactivation of Viruses by invitation of the New York Academy of Sciences. Mary D. Glynne received a grant from the Rockefeller Foundation to study wheat diseases under different climatic conditions in the United States and Canada, and afterwards represented the Department at the 9th International Botanical Congress, Montreal. As the guest of the organisers, B. D. Harrison, Mrs. M. A. Watson and E. W. Buxton also attended the Botanical Congress.

J. M. Hirst became the first recipient of the Jacob Eriksson Gold Medal awarded by the International Botanical Congress for outstanding work in Plant Pathology.

G. D. Heathcote was awarded the Ph.D. degree of London University.

Viruses and Virus Diseases

Studies on the early events in the infection of leaves comparing inocula of nucleic acid preparations and intact virus were extended to include tobacco necrosis virus in addition to tobacco mosaic virus (TMV). Nucleic acid prepared from tobacco necrosis virus by the phenol method has 20–100% of the infectivity of the parent virus compared with 0·1–1% for TMV. As with TMV, some of the changes in leaves infected with tobacco necrosis virus can be detected sooner with inocula of nucleic acid preparation than with intact virus. (Kassanis.)

Ultraviolet-inactivated tobacco mosaic virus is unusual in that it can not be photo-reactivated. By contrast, when infective nucleic acid from TMV is irradiated by ultra-violet, about 50% of absorbed radiation energy causes the kind of damage that can be reversed by exposing inoculated leaves to visible light; the remaining 50% causes irreversible damage. The manner in which the nucleic acid and protein are combined in virus particles protects the nucleic acid from the effect of ultraviolet to such an extent that 90% of the radiation is prevented from causing damage, and this includes all the photo-reactivable damage.

There is much indirect evidence that TMV separates into protein and nucleic acid as an initial step in the infection process, and the discovery that free nucleic acid is photo-reactivable suggested that direct evidence might be gained by exposing leaves to visible light at

various times after inoculation with intact virus. Photo-reactivation of the virus would be evidence that the nucleic acid had separated from the protein. The attempt failed because the effect of ultraviolet on the capacity of the leaves to support virus multiplication was so variable and was photo-reactivated to such an extent that any photo-reactivation of the inoculum within the leaves would be masked. The irradiation affected the host so much as to throw doubt on conclusions of previous workers who used radiation to measure the time when virus starts to multiply. (Bawden and A. Kleczkowski.)

Electrophoretic studies of antigen-antibody compounds showed that rabbit antibodies to human serum albumin can differ from one antiserum to another in the degree of firmness and reversibility with which they combine with the antigen. (A. Kleczkowski.)

Bacteriophage

The electrophoretic mobility of bacteria in a constant environment depends on properties of bacterial surface, so alterations in the mobility can be used to detect changes in the structure of the surface. Infection with bacteriophage increased the electrophoretic mobility of pea-nodule bacteria (*Rhizobium leguminosarum*) at pH 7. The increase occurred at about the middle of the latent period, suggesting that the bacterial surface alters at this stage of infection. (A. Kleczkowski and J. Kleczkowski.)

Tobacco rattle virus

Nucleic acid preparations made by disrupting the virus with phenol were about 5% as infective as their parent virus suspensions, and were intermediate between TMV and tobacco necrosis viruses. The properties of the infective nucleic acid preparations differed in many respects from those of their parent virus suspensions, but resembled those of nucleic acid preparations from tobacco mosaic virus. (Harrison and Nixon.)

Virus structure

Similarities in structure between tobacco rattle and tobacco mosaic viruses became evident. Certain preparations of TMV can be stained with phosphomolybdic acid to show a dark central region crossed by a system of bands about 2·5 mμ apart. Reaggregated TMV protein will show a similar staining pattern when mounted by spraying in a solution of neutral phosphotungstate, and whole virus can sometimes be made to show a similar image by treating the dried virus on the mount in hydrochloric acid vapour before adding phospho-tungstate as a fine spray. Although none of these techniques is entirely reliable, the structures observed agree well with the internal structure of tobacco mosaic virus inferred from X-ray-diffraction data. Work is now concentrated on finding a technique which will give reliable results with all samples of TMV and thus permit detailed comparison of strains. (Nixon and Woods.)

Preliminary studies with " spherical " viruses suggested that mounting in neutral phosphotungstate without any other preliminary treatment may give disappointing results, and like TMV they

will need some " softening up " before sufficient phosphotungstate to throw the internal structure into relief can be made to enter the particles. For studying details of the external shape of " spherical " viruses shadowcasting, perhaps supplemented by staining, is still the most useful method. Preliminary trials with evaporated carbon/platinum mixtures by Bradley's method (*Nature, Lond.* **181**, 875–877, 1958), in which composite rods made from finely powdered platinum and carbon are used in an evaporation source resembling that usually used for making carbon supporting films and replicas, indicate that this technique is only slightly superior to our pure platinum films and about equal to platinum–iridium alloy evaporated in the ordinary way from a tungsten filament. This work on shadowing has direct bearing on the work on clay mineral morphology, where precise measurements of flake thickness in the 1–2 mμ region of thickness are being attempted, and upon the quality of all the routine shadowed work. (Nixon and Woods.)

Soil-borne viruses

Arabis mosaic virus. This name is now used for a virus previously called raspberry yellow dwarf but now known to share many of its antigens with arabis mosaic virus (*Rep. Scottish Hort. Res. Inst.* for 1958–1959, p. 36). The virus was found damaging raspberry, strawberry and clover crops in many parts of England and in Wales. Diseased plants were patchily distributed, and the patches were closely correlated with the presence of a dagger nematode (*Xiphinema* sp.) in the soil. The virus was transmitted to pea seedlings grown in sterilised soil to which hand-picked, washed *Xiphinema* from infective soil were added, but not to seedlings grown in *Xiphinema*-free fractions of infective soil. The infectivity of soil was abolished and *Xiphinema* was killed by air-drying soil at 20° C. for a week or by various chemical treatments. The possibility that other soil-borne viruses have nematodevectors is being studied. (Harrison.)

In collaboration with the Soil Microbiology Department work began on the transmission of tobacco necrosis virus under controlled conditions. (Harrison and Jackson.) Work also began on soil-borne viruses that infect grape vines. (Dias and Harrison.)

Legume viruses

Red clover mottle virus, originally isolated from red clover plants on Rothamsted Farm, seems distinct from previously described viruses of leguminous plants. It was transmitted by inoculation of sap to many leguminous species, but *Gomphrena globosa* was the only non-leguminous species infected. The virus was not transmitted by any of the six aphid species tested or through the seed: its thermal inactivation point is 63° C., and it has " spherical " particles of about 28 mμ diameter.

Similar numbers of local lesions developed in inoculated leaves of French bean at temperatures between 12° and 24° C., but fewer developed at 28° C. and none at 32° C. The rate the virus accumulated in leaves increased with increase of temperature up to 28° C., but then decreased and the virus did not multiply at 32°–34° C.

After disruption with phenol, virus preparations retained 20% of their initial infectivity. The infectivity was presumably conferred by nucleic acid; it was abolished by pancreatic ribonuclease or by storing for a day at 20° C., treatments that have little effect on the infectivity of intact virus. As with tobacco necrosis virus, infection centres initiated by nucleic acid were more rapidly inactivated by ultraviolet-radiation immediately after inoculation, than those initiated by intact virus. Such infection centres also began to increase their resistance to ultraviolet-inactivation without the lag period of 2 hours which occurs at 20° C. with whole virus inocula. (Sinha.)

Field Beans. The spread of virus diseases into an area of field beans grown to compare different seed rates was observed in an experiment by M. J. Way. The number of virus-infected plants in insecticide-sprayed and unsprayed sub-plots did not differ, suggesting that little spread occurred within the plots. The number of plants infected per unit area of land decreased greatly as seed rate increased. The percentage infection on 10 July ranged from 7·7% leaf roll and 6·5% mosaic in sprayed plots with only 50 lb./acre of seed, to 0·3% leaf roll and 0·1% mosaic in plots with 600 lb. Leaf roll was the commonest virus disease, and symptoms were first seen on 4 June. Mosaic appeared later and spread rapidly. By the end of June most of the unsprayed plots were too damaged for the recognition of virus symptoms, but before that date the different viruses showed similar patterns of spread. (Heathcote.)

An experiment tested natural virus infection in field beans sown on 20 February, 3 April and 23 April. Mature beans are not colonised by aphids, and the number of plants naturally infected with virus diseases was highest in the plots sown later in the season. Some rows were watered every 10 days with demeton-methyl so that aphids could not colonise them, but virus spread to them as much as to untreated rows, suggesting that most of the virus spread was by winged aphids. (Heathcote and Gibbs.)

Lucerne mosaic virus. A survey showed that lucerne mosaic virus occurs in lucerne crops in all parts of Great Britain. The virus is more common in old crops, and on average 25% of the plants were infected in those crops sown before 1955.

A small field experiment showed that plots of lucerne in which 75% of the plants were infected yielded 10% less fresh weight in the year than did comparable plots with 18% of the plants infected. Yield was decreased most (20%) in the spring cut, when the diseased plants showed the brightest symptoms and were noticeably stunted. (Gibbs.)

Carrot Motley dwarf virus. No other vector than *Cavariella aegopodiae* has been found for this virus. *Myzus persicae* and *M. cymbellaria* both feed well on carrot but will not transmit. The virus persists in the vector for at least 1 week. It can be acquired by the vector in 7 hours' feeding on infected plants and transmitted during ½ hour's feeding, but a total time of at least 14 hours is necessary between start of infection feed and end of test feed, and 48 hours is optimal. Thus there appears to be a latent, or incubation, period of the virus in the vector, though the times given may not be the minimum possible.

Although the virus cannot be transmitted by sap inoculation

from carrot to carrot, it can be transmitted by aphids to *Datura tatula* and *Nicotiana clevelandii*, and inoculation of sap from these causes local lesions on *Gomphrena globosa* similar to those caused by feeding of infective aphids on *G. globosa*. Infective aphids will also cause local lesions on *N. tabacum*, from which *G. globosa* and *N. clevelandii* can be infected by inoculation, but the virus in these lesions has not yet been returned to carrot by sap inoculation or by aphids.

The virus was very prevalent in 1959, and a small field experiment at Woburn, to find the effect of infection on the yield of carrots, failed because the carrots were already infested with aphids and infected with the virus before experimental inoculations could be made. (M. A. Watson.)

Potato viruses

Results from 1958 experiments with Insecticides. In the 1958 spraying trial done in co-operation with the Insecticides Department, aphids were few, and examination of plants grown in 1959 from seed tubers showed that viruses spread only little. The percentages of infected plants in the bulk samples, which contained initially 0·8% of plants with each disease were:

	Leaf roll	Rugose mosaic
Unsprayed	4·1	2·8
Sprayed 4 times	1·0	1·2
Sprayed on 2nd, 3rd and 4th occasions ...	1·6	1·1
Sprayed on 3rd and 4th occasion	3·3	1·5
Sprayed on 4th occasion with DDT emulsion ...	3·0	2·2

Spraying dates were 4 and 16 June, 8 July and 6 August (the thiolate isomer of demeton-methyl was added to the DDT on the 3rd occasion).

In tubers taken from plants near to infected ones, the percentage incidence of virus diseases was: unsprayed, 22·4 leaf roll, 15·2 rugose mosaic; sprayed 4 times, 0·8 leaf roll, 2·8 rugose mosaic. As a sample of 642 tubers taken on the same field but away from the plots containing infected plants was free from infection, virus was not spread far from the plots, and little was introduced from other fields. (Broadbent, Burt and Heathcote.)

Although " Rogor " or " Thimet " applied when the seed was planted protected the plants from colonising aphids, they did not completely prevent the spread of viruses. However, this method of application may prove more efficient than foliar sprays, and be more acceptable to the farmer. The percentage of plants with leaf roll and Y-viruses in the five plants on either side of initially infected ones was:

	Leaf roll	Rugose mosaic
" Thimet " (individual dose) ...	2·6	19·5
" Thimet " + fertiliser	0	5·7
" Rogor " (individual dose) ...	0	18·0
Fertiliser alone	8·1	15·8

The yield of plants grown in 1959 was not affected by any insecticidal residues. (Broadbent, Burt and Heathcote.)

Aphid trapping in potato crops in 1959. Nine sticky traps were operated in unsprayed crops near sprayed ones in different parts of England. Aphids were very numerous during June. Six times as many aphids (38,900) were trapped as in 1958 (6,684), although there were two fewer traps operating. *Myzus persicae* were exceptionally common in some areas in September when they were colonising their winter host-plants. (Heathcote.)

Cereal and grass viruses

Wheat striate mosaic was again isolated from oats and wheat at Rothamsted, and it also damaged wheat at Tivetshall, near Norwich, where 10% of the plants in a large area of crop were infected. *Delphacodes pellucida* collected at both sites were carrying the virus. The ability of some of our inefficient vector races to transmit virus can be increased by pricking the anterior abdomen, using the technique described by Storey for converting non-vectors of maize streak mosaic virus into vectors. The virus is optimally transmitted by plant hoppers that feed on infected plants as nymphs or inherit virus from their parents. Females that feed on infected plants as adults transmit only infrequently to plants, and they very rarely transmit to their nymphs through the eggs, even though the interval between virus acquisition and mating is long enough for the virus to become transmissible to plants.

We could not confirm that nymphs or eggs inherit virus from females that are unable to infect plants. If the virus can remain latent in some females for a generation, none of the races we are now using seem to have this ability. (Watson and Sinha.)

Infected eggs and embryos were examined in attempts to ascertain the nature of the damage that often leads to their death. Attention was paid particularly to the mycetome which seems important to the growth of the egg at the stage when infected ones often begin to die, and in which there was some slight evidence of deterioration and deformation of the cells. Attempts in collaboration with the Soil Microbiology Department to culture the mycetome *in vitro* have probably failed, although sterile cultures, in which the cells survived, were made, and a yeast that appears not to have been previously described was isolated. (Watson, Ikaheimo and Parle.)

Barley (cereal) yellow dwarf. Following the *Rev. appl. Mycol.* the name barley yellow dwarf virus will be used in future for the virus previously referred to as cereal yellow dwarf.

The virus was common in field crops, though not so common or so damaging as in 1958. The results of field experiments made in 1956–58 were further examined to try to find the reason for variability in response to infection between seasons and between crops. A suggestion that the time of infection relative to the time of tillering is responsible was not confirmed. In 1957 even the earliest infection (22 April) neither inhibited tillers nor killed the main shoot already formed. In 1958 plots infected around the time of tillering lost yield at the same rate as those infected later. The rate of loss of grain was positively correlated with the severity of leaf symptoms (score for yellowing and measurement of plant height), coupled with the length of time for which the plants were infected. This relationship

held for all cereals and for both virulent and avirulent viruses. The loss of yield seems to result from decrease in total leaf area and possibly from a lessened efficiency of assimilation, but not from the loss of any particular flowering organs, though these are decreased in proportion to the rest of the plant. Wheat possibly suffers more than other cereals from later infection because it matures later and more of the contribution of assimilate from the glumes is lost than with the other cereals.

In 1957 we could not transmit virus from an apparently infected oat crop at Hexton in Bedfordshire by *Rhopalosiphum padi*. Samples of grasses, groundkeeper oats and barley from a neighbouring field were tested again in 1959 and found to contain a virulent virus apparently identical with the virulent " Kent " virus isolated previously. This virus was not transmitted by *R. padi*, but was readily transmitted by *Metapolophium dirhodum* and less readily by *Sitobium avenae* and *S. fragariae*. This agreed with the results of workers in the United States, who have reported specific transmissions of individual barley yellow dwarf virus by the "Applegrain " and " English-grain " aphids, We further found that the avirulent Rothamsted virus was rarely if ever transmitted by *S. avenae* and *S. fragariae*, although it had been so when first obtained in 1954. Another and more virulent isolate from Rothamsted was transmissible by *S. avenae* but not by *R. padi*. The " Kent " isolate was not transmissible by *S. avenae*, though *S. fragariae* and *M. dirhodum* occasionally succeeded, but it was very readily transmitted by *R. padi*. Finally, a plant sent from Bristol early in 1959 contained virus that was readily transmitted by all four aphids, though least successfully by *S. avenae*. General observations suggest that there are many yellow dwarf viruses transmissible by different permutations and combinations of possible vector species and that they may change from one to another when the predominant aphid species changes. Hence the loss of ability of the Rothamsted and the Kent isolates when transmitted only by *R. padi* to be transmitted by the other aphids and the efficient transmission of the Hexton virus by *M. dirhodum*, which was the dominant aphid at the time of the virus outbreak.

Cocksfoot streak. This virus, supplied by Dr. Kenneth M. Smith from the original stock he described in 1952 was transmitted to several varieties of cocksfoot and to Italian ryegrass by inoculation of sap. *M. persicae* transmitted best after fasting for some hours and feeding for only 2 minutes on infected leaves. The virus persisted less than 1 hour in the vectors when they were feeding on immune hosts. *Hyalopterus humulis*, which appears to have only cocksfoot as a host, is a vector; *S. avenae* and *M. dirhodum* also transmitted in short feeding periods, but *R. padi* and *S. fragariae* did not.

The presence of rod-shaped particles in infected sap, and the similarity of the symptoms to those of ryegrass mosaic, suggested for a time that the viruses might have some relationship, but this seems not to be true.

The virus was isolated from cocksfoot stands at Woburn, at the Grassland Research Institute at Hurley and the Welsh Plant Breeding Station, Aberystwyth. (M. A. Watson and Mulligan.)

Fungi and Fungus Diseases

Cereal diseases

Long-term experiments. Broadbalk was not drilled until December, and was much less affected by eyespot (*Cercosporella herpotrichoides*) than usual. The 1st, 2nd, 3rd, 4th and 8th consecutive wheat crops after a 1-year fallow averaged 8, 20, 32, 21 and 16% straws with eyespot, 2, 10, 11, 12 and 7% with severe lesions; 0, 4·6, 11·3, 7·0 and 9·9% straws had take-all (*Ophiobolus graminis*) on the roots. Take-all was slight, for though many seminal roots were infected, the fungus did not spread to the crown or crown roots. An exceptionally low plant number recorded in spring on some plots of the first crop after fallow did not seem to be caused by fungi. Mildew (*Erysiphe graminis*), unlike last year, was very slight. In the six-course rotation experiment, eyespot incidence was about average for wheat sown in October, and below average in the alternate wheat and fallow experiment sown in late November. Recent changes in the alternate wheat and fallow experiment provide subplots with various sequences which show consistent differences in eyespot and take-all. For instance, sown at the normal rate, wheat following two consecutive crops sown at $\frac{1}{3}$ bushel/acre had 40% straws infected by eyespot, and 6% with take-all on the roots, whereas those following 1 and 3 years' fallow had respectively 20 and 6% with eyespot, 0·7 and 0% with take-all. The interesting, though economically unimportant, disease caused by *Gibellina cerealis* was more than usually common in this experiment, the only place where it is known to occur in Britain.

Brown foot rot (*Fusarium* spp.) was more common than usual at Rothamsted. In many crops it caused whiteheads and occasionally patches of dwarfed prematurely ripened plants with shrivelled grain. (Glynne and Cox.)

Experiments on factors limiting yield. Cappelle wheat gave very different responses to treatments in two experiments on different fields. One experiment, in which it was hoped to include optimum treatments, followed two consecutive crops of early potatoes which received dung. Virtually free from eyespot and take-all, the crop looked superb until a storm on 10 July caused extensive lodging. The effects of different treatments followed the normal pattern. The mean per cent areas lodged at harvest for plots sown in October, November and January respectively were 94, 66 and 14%, for those sown at 2, 3, and 4 bushels/acre 46, 57 and 70%, and for those receiving respectively 3 and 6 cwt. " Nitro-Chalk " in spring 42 and 73%. The mean yield of grain was 50·6 cwt./acre. Yield responses expected from early sowing and high nitrogen were decreased by lodging, and no treatment significantly affected mean yield. However, plots sown in January were less severely lodged and showed a significant response to seed-rate, 4 bushels seed/acre yielding 5·6 cwt./acre more than 2 bushels. The extra nitrogen tended to decrease yield in the earlier sown crops, but the effect reached the level for significance only in November.

In the other experiment on less fertile land, Cappelle wheat followed two spring-sown barley crops. Eyespot was slight; take-all, observed as early as February, was prevalent and, though it did not

cause severe symptoms it is likely to have affected yield. There was negligible lodging. Mean yield of grain was 40·7 cwt./acre. Plots sown in January yielded 5·9 cwt./acre less than those sown earlier, and there was the large response of 7·2 cwt./acre to the heavier dose of nitrogen. Although the highest seed-rate yielded consistently more than the lowest, the effects did not reach the level for significance. (Glynne and Slope.)

Cereal–beans rotation experiment. In this account of the cereal–bean rotation experiment the following abbreviations will be used: W = winter wheat, sW = spring wheat, B = barley, O = oats. In the first series begun in 1957, Koga II spring wheat grown in 1959 after the following crop sequences WW, sWW, OW, WO had respectively 12·2, 8·5, 20·1 and 2·6% straws with take-all in June and yielded 32·0, 32·4, 29·2 and 32·0 cwt. grain/acre. The highest incidence of take-all followed the sequence OW, on which the wheat in June 1958 had only 8·4% of the straws with take-all, whereas the wheat in the sequences WW and sWW had 88·8% infected. This is another example of the tendency for take-all to reach a peak and then decline. In the second series, begun in 1958, Cappelle winter wheat sown in January after W, B, sW and O had 11·4, 41·1, 29·1 and 2·4% straws with take-all and yielded 37·4, 31·9, 37·5 and 41·9 cwt. grain/acre. As in 1958 there was very little take-all in wheat following the non-susceptible oat crop. (Slope).

Pots holding 36 lb. of soil were used in an experiment, begun in 1953, in which wheat is grown either continuously or after different periods under fallow. Take-all has consistently increased in successive wheat crops and been most severe in the 3rd, in which yields have been very low. In subsequent crops the disease has been less severe and yields have risen. Thus in 1959 the 1st wheat crop after 2 years fallow had little take-all and yielded 18·8 g./pot, the 3rd had very severe take-all and yielded 6·6 g., and the 7th with moderate take-all yielded 16·0 g. (Glynne.)

Survival of *Cercosporella herpotrichoides*, estimated by counting the straws on the soil surface which produce spores of the fungus when incubated in the laboratory, was measured on two Broadbalk plots in January and February. On Section II, where wheat was grown in 1958, spore-producing straws averaged 1·4/sq. yd., and 5·8% of the plants in the 1959 wheat crop were infected in May. On Section VA, fallow in 1958, there were only 0·2 spore-producing straws/sq. yd.; no infected plants were found in May. (Cox.)

Incidence of take-all on Broadbalk. The soil microflora associated with wheat was studied to determine whether the low incidence of take-all on Broadbalk results from microbiological activity. The fungi in the soil, in the rhizosphere and on the root surface were surveyed in a pot experiment using soil from: (*a*) the unmanured plot of Broadbalk after the 4th successive wheat crop, which had 5% straws with take-all, and (*b*) an unmanured sub-plot of the Hoosfield Wheat and Fallow Experiment after the 3rd successive wheat crop, which had 31% straws infected. Similar surveys were made in the field on plots with corresponding crop sequences. Take-all developed more rapidly and severely on plants in the pots containing the Wheat and Fallow soil than on those in the Broadbalk soil; in the field there was little take-all on either the Wheat

and Fallow or Broadbalk. In pots and the field the total number of fungi in the rhizosphere was higher in Broadbalk soil than in the Wheat and Fallow soil, a difference largely accounted for by the number of Penicillia. (Cox.)

Potato blight

Experiments into the nature of haulm resistance to potato blight were previously confined to the varieties Up to Date, King Edward, Majestic and Arran Viking, which have shown only small differences in the rates of defoliation by blight. The additional varieties, Ackersegen, Ås and Ontario, selected for their blight resistance from varieties grown in small field plots in 1958, were included in experiments in 1959.

Blight was found in some plots on 12 August, and to ensure a more uniform distribution of the disease all plots were infected artificially. Weather favourable for spread occurred sporadically in August, but a dry September stopped further development of the epidemic. In marked leaves frequently examined, destruction followed a similar pattern in all varieties; blight on the leaf lamina advanced through petioles, so causing non-infected leaflets to die into the stem. Some infections in Ackersegen were arrested when still in the leaf lamina. In King Edward and Up to Date, lesions quickly girdled the stem and affected the foliage above, whereas in Majestic, Arran Viking and Ås, although stem lesions occurred, few girdled the stem, and those that did were either near the top of the plant or on the weaker axillary shoots. The 50% level of destruction by blight as assessed on the marked leaves was reached 2, 3, 8 and 14 days later in Majestic, Arran Viking, Up to Date and Ås respectively, than in King Edward. Thirty-three per cent of the leaflets of marked leaves were destroyed by blight in Ackersegen, 63% in Ås and about 85% in the other varieties.

Laboratory studies with Up to Date, King Edward, Majestic and Arran Viking showed that the under surfaces of leaves were usually more susceptible to infection than the upper surfaces. Detached leaves of these varieties differed little in their susceptibility to infection or in the rate at which the fungus advanced in the leaf lamina.

Lesions spreading from the base of the terminal leaflet destroyed the leaflets quicker than those from the tip, and the time for destruction from either site increased in the order King Edward, Up to Date, Majestic and Arran Viking. Infection advanced into and girdled the petiole in Up to Date and King Edward rapidly, but was much slower in Majestic. In Arran Viking, Ackersegen and Ås the infection was arrested within the petiole.

Sporulation on different varieties differed. Up to Date produced more spores more rapidly than did Arran Viking when non-sporing lesions of similar size (10 mm.) were kept at a high humidity. After 5 hours at 15° C. aerial hyphae were abundant in Up to Date and a few sporangia had formed, whereas in Arran Viking hyphae were still fewer. After 10 hours, sporulation was intense in Up to Date but slight in Arran Viking. King Edward behaved like Up to Date, and Ackersegen and Ås like Arran Viking. The varieties slow to produce spores were those whose infected cells died rapidly, and rapid sporulation was correlated with slow death. The rate

of necrosis may interfere with spore production by limiting the area able to produce spores, and may be a factor in determining the width of the sporing annulus, which is narrow in these resistant varieties.

Plants in pots were used to assess the blight susceptibility of 45 commercial varieties of all maturity groups. Tests included susceptibility of leaf and leaf axil to infection, sporing capacity and the rate of advance of the fungus within leaf tissue. Early varieties were the most susceptible in all respects, and generally resistance increased with the lateness of the variety. (Lapwood.)

Aerobiology

The work on the mechanisms of distant air-dispersal of fungus spores was continued in conjunction with the Meteorological Office. On several occasions traps operated in aircraft showed that the maximum concentrations of *Puccinia graminis* spores were at 3,000–5,000 feet. The catches were closely correlated with air trajectories from Southern Europe and support the conclusion that before mid-July uredospores caught in Britain are of foreign origin. Previously our spore-trapping methods were restricted to the visual recognition of air-dispersed spores, but we are developing cultural methods to measure the proportion of viable spores and details of their movement in splashed or dripping water. (Hirst and Stedman.)

Clubroot of crucifers

A study begun this year seeks: (1) better differential hosts for the three races of *Plasmodiophora brassicae*—(i) our standard strain, (ii) from Agdell Field and (iii) from Norway; and (2) different types of response to infection as influenced by host species or variety.

Thirty-five sorts were tested, but so far the search for better differential hosts has been disappointing. The three races behaved much as before; race (i) had little or no effect on turnips and swedes, which were, however, severely clubbed by races (ii) and (iii). No turnip or swede variety tested showed any pronounced resistance to (ii) and (iii). Race (iii) was usually more virulent than the others but not always so. Race (i) tended to club cabbage rather more than (ii), and (iii) was intermediate. A series of strains of several cultivated mustards, from various parts of the world (ex Colman's), were uniformly and highly susceptible to all races. Strains of *Brassica nigra* were exceptional in that the population seemed to be heterogeneous in their response to Plasmodiophora, and some plants became severely diseased whereas others were unaffected. The proportion of susceptible plants differed with host strain. An English variety of rape was severely clubbed by all three races; a New Zealand club-resistant rape was unaffected by (i), a few plants were moderately diseased by (ii) and all plants were severely diseased by (iii). This was the most striking effect observed. Another differential effect was that a few plants of *Matthiola bicornis* were clubbed by race (ii) but were unaffected by (i) and (iii). *Matthiola annua* remained unaffected by all three.

Most plants, other than those of the cabbage group and the

mustards, formed galls that were nodular in appearance, although the nodules were often fused and irregular. *Malcolmia maritima*, however, tended to form many separate nodules on short laterals. An interesting feature of some swede varieties was that with race (i) fairly numerous very minute galls were formed on fine rootlets. This type of symptom has been mentioned in the literature and warrants further study. (Macfarlane.)

A series of complexes of copper, zinc and cobalt with gluconic acid were tested on clubroot. Plants were grown in small, white, polythene pots, which rested inside glass beakers, leaving gaps between the bases of the pots and the bottoms of the beakers. In this way leachings containing fungicide could be conserved and returned to the soil. Increasing doses of copper compound tended to decrease dry weight of clubs but increased weight of fibrous roots, tops and total dry weight. The zinc compound apparently hydrolysed in water and zinc was probably present in the soil as hydroxide. This completely suppressed clubroot with yields of tops closest to those of uninoculated controls. The cobalt compound was about as effective as copper or zinc in preventing clubroot, but was more toxic. Effects differed slightly according to whether the host plant was cabbage or brown mustard (*Brassica juncea*). (Macfarlane and Gourlet.)

Fusarium diseases of peas

Varietal resistance. Further tests for wilt-resistance in peas, made in fields at Yaxley, Peterborough and at Coggeshall, Essex, divided 35 pea varieties into three groups: 8 were very susceptible, 4 susceptible and 23 were resistant. In earlier work, isolated healthy plants appeared among some susceptible varieties, and seed from these was sown at Yaxley and Coggeshall. 47% of the plants from these were wilt-resistant, and only three were not true to varietal type. Selection, therefore, quickly provides resistant stocks from important susceptible varieties, such as Feltham First, Lincoln, British Lion and Little Marvel. In tests designed to control pea-seedling losses, seed of varieties Onward and Dark Skin Perfection were treated with " Captan ", " Thiram " or " CoBH " (quinone-oxime-benzoylhydrazone). " Thiram " increased emergence by 30%, " Captan " by 46% and " CoBH " by 24%. Subsequent yield was as much as 89% higher in the wilt-resistant Dark Skin Perfection. None of the treatments affected wilt in the variety Onward.

Rhizosphere studies. Extending the work on interactions between rhizosphere micro-organisms which grow on pea roots revealed that the most common fungi were *Gliocladium roseum*, *Penicillium* spp., *Fusarium oxysporum*, *Fusarium solani*, *Mortierella* spp., *Rhizopus stolonifer* and *Trichoderma viride*. From 137 morphologically different isolates, 14% strongly inhibited pathogenic *Fusarium oxysporum*, 42% were considerable inhibitors, 29% only slightly so and 15% not at all. *Gliocladium roseum*, some bacteria and other strains of *Fusarium oxysporum* were among the strongest inhibitors. When grown in media containing rhizosphere extract, pea root exudate or both, their ability to inhibit the pathogenic

Fusarium greatly increased. Different isolates of *Gliocladium roseum* and of *Fusarium oxysporum* inhibited the pathogenic *Fusarium* to different extents, showing that they contain physiologic strains that may act differentially towards *F. oxysporum* in the rhizosphere. Although there were more micro-organisms/g. of dry soil in the rhizosphere of the wilt-susceptible variety Onward than of the wilt-resistant variety Alaska, there was no difference, either quantitative or qualitative, between the two varieties in the organisms that could inhibit the *Fusarium*. Neither those rhizosphere micro-organisms that were more prevalent during the time that *Fusarium* invades the host roots nor the ones themselves most strongly stimulated by pea-root exudate were prominent among the group most ántagonistic towards the *Fusarium*. This implies that competition between pathogenic *Fusarium* and the other rhizosphere flora for nutrients in root exudates may be at least as important as overcoming antibiosis in maintaining successful growth of the pathogen near host-root surfaces. Although these results were obtained *in vitro*, they suggest that rhizosphere soil extract and microbial metabolites together deter the growth of *F. oxysporum* f. *pisi* near pea roots, and that the growth-promoting effects of root exudate from the wilt-susceptible pea variety Onward are partially offset by its ability to increase inhibition by some of the other rhizosphere inhabitants. (Buxton.)

Effects of previous cropping on pea wilt and on F. oxysporum *in naturally infested soil.* The rate physiologic races of *F. oxysporum* f. *pisi* increase in pea rhizospheres in naturally infested soil was studied by growing peas up to different ages and by growing them repeatedly in the same soil. Rates of decline of soil populations of the *Fusarium* in the absence of peas after different cropping treatments were also investigated. In rhizospheres of the wilt-susceptible variety Onward the *Fusarium* increased from 10,000/g. dry soil on 2-week-old, to 195,000/g. on 5-week-old plants, falling to 150,000/g. after 7 weeks. In the variety Alaska, which resists race (i), the corresponding figures were 6,000, 263,000 and 142,000. Of the total rhizosphere flora isolated, *Fusarium oxysporum* formed 8, 35, 54, 61, 60, 55, 32 and 61% after each week up to 8 weeks on Onward, and 12, 19, 41, 71, 59, 60, 35 and 69% on Alaska. The effect of pre-cropping with Onward or Alaska on subsequent wilt in Onward depended on the age and type of the previous crop. Wilt occurred more rapidly in soils precropped with Onward than with Alaska, but wilt developed most rapidly in soils which had previously grown Onward for 2 or 6 weeks. Inoculation tests using the rhizosphere isolates showed that only a small proportion were pathogenic, indicating that the rhizosphere effect can act equally on pathogenic and saprophytic Fusaria. High soil populations of *F. oxysporum* were also produced by repeated cropping of soil with peas of either variety. From soils in which pea cropping had been repeated from once up to six times the decline in populations took 8 weeks to fall from 123,000 to 25,000/g. of dry soil whether the cropping was with Onward or Alaska. The effect on wilt and *Fusarium* of crops other than peas laid out as a four-course rotation between wheat, a root crop, barley and fallow or peas, in outdoor microplots containing naturally infested soil, is being studied over a long period. (Buxton.)

Sitka-seedling diseases

In experiments by the Chemistry Department, done in co-operation with the Research Branch of the Forestry Commission, on the growth of seedlings of Sitka (*Picea sitchensis*), difficulties have arisen from disorders not correlated with changes in levels of the applied nutrients. These troubles are partially controlled by such materials as formalin and chloropicrin, which has led to the supposition that they may be caused by soil-borne plant pathogens. To study this possibility, the development of micro-organisms on roots of Sitka seedlings taken from an experiment at Old Kennington, near Oxford (a nursery started in 1925), was examined on 15 occasions through the growing season. Three distinct diseases occurred; first, a pre-emergence and immediately post-emergence damping-off, which was followed in mid-summer by a sudden browning of the plants; during the early autumn the plants became stunted but with no discoloration. Emergence in plots treated with formalin was 44%, with chloropicrin 33% and in untreated was only 16%. Counts of browned plants later, on three occasions, showed 6·4% on formalin-treated, 10·5% on chloropicrin-treated and 24·7% on untreated plots. The autumn stunting was confined to plots treated with formalin.

All three diseases can occur on plots that have received formalin annually for the past 5 years, so any pathogenic organisms responsible may be brought in with the seed, or re-invade the soil from adjacent land or both. Plating-out seed on agar medium revealed the presence of nearly all the organisms also found on roots of plants from the field, so the rhizosphere flora may be derived from seed alone. Whether rapid re-invasion depends on adaptation in some of the soil fungi towards tolerance of high levels of formalin and chloropicrin is being studied. The prevalence of the 18 different micro-organisms found both on roots and in soil away from roots during the growing season fluctuated considerably. Striking changes occurred in *Pythium*, abundant at first but almost absent later, in *Fusarium oxysporum*, rare at first and abundant later, and in *Trichoderma viride*, which reached a peak in later August. Other fungi also changed in abundance as the season advanced. From the isolates made from the 13,200 root fragments plated out during the season, 96 fungi and bacteria were tested for pathogenicity to Sitka seedlings. Of these, *Pythium* spp. *Fusarium oxysporum* and an unidentified bacterium caused symptoms similar to those seen in the field. A higher percentage of the *Pythium* isolates made earlier in the season were pathogenic than of those made later on, and the *F. oxysporum* isolates made in mid-summer contained more pathogens than at other times. This evidence, together with the symptoms observed, strongly suggests that *Pythium* causes most of the damping-off, and that the browning is mostly caused by *F. oxysporum*. From the later samples, several isolates of *F. oxysporum* and *Fusarium roseum* stunted seedlings inoculated in the glasshouse. (Buxton.)

Sitka-seedling diseases also occur at the nurseries in Ringwood, Hants, and Wareham, Dorset. Damping-off has previously been recorded at Ringwood, but browning in the newest part of Wareham

was noticed only during 1959. At Wareham plots treated with compost (made from bracken and hop waste) had many more browned plants than did fertiliser-treated plots. Plants taken from both localities had disease symptoms similar to those seen at Old Kennington, and plating out roots on agar media revealed that by far the most predominant fungus was *Fusarium oxysporum*.

In a new section at Kennington, Oxford, started in 1951, similar plots had browned plants for the first time on both compost- and fertiliser-treated plots. At both Wareham and Kennington healthy plants from all plots were examined and none had *Fusarium* on the roots except from one fertiliser-treated plot at Kennington, which had plants with roots yielding 12·5% *Fusarium*.

Analysing soils from Old Kennington and Ringwood by the dilution plate method shows that soils treated with formalin contain no *Fusarium oxysporum*, but untreated soils, in all of which seedlings develop browning, contained an average of 150,000 propagules of the fungus/g. dry soil At Ringwood one untreated area has grown Sitka seedlings for 6 years, from repeated spring sowings, without a break, and without disease. No *Fusarium oxysporum* was found in soil samples or on roots of plants from this area. Microscopic examination of roots of diseased plants shows the presence of several fungi, both as mycelium and spores. *Fusarium roseum, Cylindrocarpon radicicola* and *Rhizoctonia* sp. are prevalent, yet the two last-mentioned fungi are only rarely revealed by plating out roots on agar media. In addition, direct examination of soil after centrifuging suspensions and filtering microorganisms through a Seitz filter on Oxoid membranes also shows fungi that might be missed by plating techniques. These direct observation methods are being extended and standardised. (Buxton and Ram Reddy.)

Variation in Verticillium albo-atrum *from hop*

Verticillium albo-atrum has no known sexual stage, but it seems to vary pathogenically, and to understand how it produces novel progeny work was begun to see whether genetic recombination occurs without sex. Both dark and hyaline wild-type strains of the fungus can be isolated from infected hop plants, and cultures established from single hyphal tips yield conidia that produce either dark or hyaline colonies. Other authors have demonstrated that over 98% of the conidia produced by their isolates were uninucleate, so the hyphal tips seemed likely to be heterokaryotic, but the term should not be applied until it has been confirmed that colour is determined by the nucleus. It was therefore necessary to synthesise heterokaryons composed of strains labelled with known nuclear markers, and to determine whether heterokaryosis would recombine colour with these markers.

Nutritionally deficient mutants were isolated after exposing cultures to ultraviolet radiation. The mutants were characterised by replica plating and auxanography, and almost all the conidia were uninucleate. When conidia of a hyaline strain requiring methionine and biotin were mixed with spores from a black isolate that required adenine, and incubated on Czapek–Dox agar medium which supplied none of these compounds, the mixed inoculum produced

slow-growing sectors. Some hyphal tips taken from these areas produced conidia which required either adenine or both methionine and biotin, but a sample of about 1,000 spores contained none able to grow on unaugmented media. The double auxotrophs were always hyaline like the parent, but the adenine requirers from the heterokaryon varied from light grey to black, a greater colour range than was observed in single-spore isolates from the original pure culture of the adenine-dependent strain. The results confirmed that heterokaryosis occurred, but did not prove that the colour was controlled at nuclear loci.

A sample of several million conidia from the heterokaryon included a few able to grow on unaugmented Czapek–Dox agar (prototrophs). If these colonies arose from heterokaryotic conidia they would be expected to produce further heterokaryotic spores at the low frequency observed in the first selection. However, they produced only prototrophic conidia when a spore suspension was spread on Czapek–Dox, but a similar sample of spores incubated on a weakly augmented medium produced an equal number of wild-type colonies; they also produced a few which were slow growing. These had nutritional requirements and included some recombinant phenotypes. By using such a selective system all three nutritional markers were recovered. Because they all came, indirectly, from a single prototrophic conidium which was almost certainly uninucleate a heterozygous diploid phase could be inferred, suggesting that a system resembling parasexuality allows genetic recombination in *V. albo-atrum*.

Certain adenine-requiring mutants rarely produce aerial conidiophores unless they are grown on a medium containing a high adenine concentration. These produce conidia in pionnotes, and it can be inferred that this is a pleiotrophic effect of mutations which block adenine synthesis at a stage preceding the synthesis of inosine. There was no evidence in the parental strain of morphological variation directly attributable to mutations affecting methionine and biotin synthesis, but these mutations may have such effects when combined with other genes, and this may account for certain recombinants having characters common to *Cephalosporium* species. (Buxton and Hastie.)

Mycofloral succession in hay

Work on the mycoflora of hay was restricted to the study of the air-borne fraction, as inhalation of spores appears to be the cause of certain human and animal diseases associated with mouldy hay. This fraction is assessed by shaking a known weight of hay for 3 minutes at a wind speed of about 4 metres/second in a small wind tunnel. The spore-laden air is sampled by several methods. The Cascade Impactor gives a visual estimate of the total number of spores (expressed as millions/g. dry weight of hay). Viable fungi, actinomycetes and bacteria are isolated in culture with the Henderson Impinger or the Andersen Sampler. Malt and nutrient agar plates are incubated at both 24° C. and 40° C.

Samples of hay and straw from different parts of the country were examined for their spore content. Good hays had as few as 0·4 million spores/g.; poorer hays had up to 20 million *Aspergillus*

glaucus spores. Hays associated with human and animal diseases had up to 85 million fungus spores or 1,500 million bacteria and actinomycete spores/g. The fungi present in these bad hays are generally thermophilic species, such as *Absidia ramosa, Mucor pusillus, Aspergillus fumigatus* and *Monotospora lanuginosa.*

Farmers know that, when hay is baled too wet (moisture content much more than 20%), it will become hot, lose moisture and go mouldy. There is also some rise in temperature during the normal maturation of hay. To study the succession of the microbial flora on hay during maturation, hay from the mixed ley on New Zealand field at Rothamsted was baled at different moisture contents. After baling at 42% moisture the temperature rose to over 60° C. in 3 days and remained steady for over a week, during which moisture was lost, fungi, including *Aspergillus fumigatus* and *Absidia ramosa,* developed up to 6M spores/g. and actinomycetes and bacteria up to 500 M. Baled at 28% temperatures rose to over 40° C. and 40 M *Aspergillus glaucus* spores developed. Baled at 16% moisture it reached 30° C., but very few spores of any kind developed. (Gregory and Bunce.)

NEMATOLOGY DEPARTMENT

F. G. W. Jones

In July R. D. Winslow gave a course of lectures at North Carolina State College on the ecology of free-living and plant parasitic nematodes. H. R. Wallace attended the Botanical Congress in Montreal, as the guest of the organisers; M. T. Franklin, J. B. Goodey, F. G. W. Jones and A. M. Shepherd attended the Fifth International Nematology Symposium in Uppsala, Sweden; J. B. Goodey was elected to the editorial board of *Nematologica*. In November an exhibit on chrysanthemum eelworm was staged at the National Chrysanthemum Society's show in London. The work of the department continues to be hampered by overcrowding in the laboratory and by lack of proper glasshouses and soil-handling facilities.

Systematics

Early in the year Dr. R. S. Pitcher of East Malling Research Station and Mr. F. C. Peacock of Imperial Chemical Industries, Jealott's Hill Laboratory, brought us specimens of *Xiphinema* from separate localities. These appear to be *X. diversicaudatum* as originally described by Micoletzky, not the species described in the standard monograph on the genus by Thorne. The range of variation of the male, female and immature stages was studied in detail on specimens from many sites. The tail usually bears a short, finger-like peg, but a few specimens from one site have smooth tails. Had these been found by themselves, they would have been considered a distinct species. The numbers of laterial pores on the tail and the sub-ventral series in the male anterior to the anus, which have been used as diagnostic characters in other species, vary widely. This species of *Xiphinema* has been shown separately by Harrison, Plant Pathology Department, Rothamsted, Dr. C. H. Cadman, Scottish Horticultural Research Institute, and Dr. A. F. Posnette, East Malling Research Station, to be a plant virus vector. (Goodey, Hooper.)

As usual, many specimens were received for identification, among them a series of samples associated with virus diseased sugar cane which yielded several interesting nematodes, including *Xiphinema pratensis*, *Tylenchorhynchus martini*, *Pratylenchus zeae*, *Rotylenchoides* sp. and *Trophurus* sp. Samples of manila hemp roots (*Musa textilis*) from North Borneo yielded *Pratylenchus coffeae*, new species of *Pratylenchus* and *Trophurus*, and *Tylenchulus semipenetrans*, the citrus nematode, for which manila hemp is a new host record. Work also continues on the genera *Meloidogyne*, *Aphelenchus* and *Aphelenchoides*. (Franklin, Goodey, Hooper.)

A visiting worker, Mr. W. C. Clark of New Zealand, began a study of the nematode fauna of New Zealand based on nematodes extracted from a considerable range of soils whose histories and physical properties are well known. Many are from volcanic ash soils of known

age. Nematodes can often be run down to known genera but cannot be placed in known species, and there are interesting differences in the dimensions of one species that occurs in different localities.

Feeding Mechanisms of Nematodes

Many of the difficulties of observing nematodes spring from their microscopic size and the obscurity of the environments in which they are found. Special techniques are therefore necessary to make observations which, with most insects or other larger animals, could be made with the naked eye or with low-power magnification. Ciné and electronic flash photography coupled with the development of suitable observation chambers has made possible the recording of nematode activity, movement and feeding, and has thrown some light on the function of oesophageal muscles and valves during the act of feeding. Films were made of representative fluid feeders with mouth stylets and particulate feeders with and without oesophageal valves. Two rhabditids have so far been studied in detail. Films and observation of *Aphelenchus avenae* feeding on fungal hyphae indicate that hyphal walls are punctured solely by thrusting the stylet; the anterior of the nematode does not adhere to the hypha during penetration. Films were also made of predators feeding on white, immature females of the clover cyst nematode, *Heterodera trifolii*. These included the enchytraeids (*Fridericia*), large dorylaims and the spring-tails, *Onychiurus*, *Achorutes* and *Folsomia*. (Doncaster.)

Migratory Soil Nematodes

Routine sampling of rotational experiments on the heavy soil at Rothamsted and the light soil at Woburn continued and sampling of the classical experiments started. Samples were also examined in connexion with the work on nematodes as virus vectors (Harrison, Plant Pathology) and with that on forest-tree nurseries (Benzian, Chemistry). There is no evidence that plant parasites are numerous in the nurseries, but most have large populations of *Tylenchus* spp.; the highest numbers (over 700/25 g. soil) were found in compost-treated plots, where they may be feeding on fungi.

Various chemicals were tested as accelerators in attempts to improve extraction of soil nematodes from Baermann funnels. Potassium dichromate was the best, but none was very effective. Improved extraction from samples artificially infested with beet eelworm larvae was obtained by suspending electric-light bulbs above the funnels to give a temperature gradient from the soil surface downwards. A modification of the funnel technique, in which small quantities of naturally infested soil were placed on paper tissue and supported by means of wire gauze approximately $\frac{1}{2}$ cm. above the bottom of a petri dish containing $\frac{1}{2}$ cm. of water, yielded five times as many nematodes as unmodified Baermann funnels and three times as many as funnels heated above by an electric lamp. The petri-dish technique, however, is not equally suitable for all nematodes; *Xiphinema*, *Longidorus* and possibly other large Dorylaimoidea are inefficiently extracted. Placing the petri-dishes in an atmosphere of oxygen did not increase the recovery of nematodes. (Winslow.)

Cyst-forming Nematodes of the Genus *Heterodera*

Potato-root eelworm (Heterodera rostochiensis)

Joint work on the chemical nature of the hatching factor which diffuses from potato roots into soil continued in collaboration with A. J. Clarke (Biochemistry Department). Over 500 gallons of crude potato-root diffusate from potted plants were produced during the year, together with smaller quantities of tomato and rape diffusates from germinated seed and pot plants. (Nelson.)

More is now known about the distribution in England and Wales of biotypes of potato-root eelworm capable of infecting crosses between *Solanum tuberosum* spp. *tuberosum* and *S. tuberosum* spp. *andigena* that contain the resistant gene H. Additional populations were tested at Rothamsted and in collaboration with the National Agricultural Advisory Service. More than half the populations tested so far, whether drawn from fields, gardens or glasshouses, contained appreciable numbers of females able to attack the resistant plants. Most populations tested from East Anglia and Northern Ireland did not break resistance, whereas population from the silt lands around the Wash, from the East Midlands, from Lancashire and from the Channel Islands mostly did. In most fields in these areas commercial varieties containing the gene H would be valueless immediately or after growing one or two crops. Elsewhere such varieties, which may be available shortly, should have a longer useful life. Pot tests indicate that the proportion of resistance-breaking females increases each time resistant potatoes are grown. The rate of increase observed suggested that resistance-breaking of this type might depend on a simple recessive gene (aa). Attempts were made to cross resistance-breaking (aa) and non-resistance-breaking populations (AA) in such a way that males of the latter type (A) would be in great excess and so give progeny (i.e., eggs within cysts) of the heterozygous type (Aa). If the hypothesis that only the double recessive (aa) breaks resistance were correct, heterozygous progeny (Aa) should not reproduce on resistant plants. In fact, reproduction occurred which suggests that the hypothesis is false. Mass crossing, however, is not a satisfactory procedure, because mating is uncontrolled. Controlled mating *in vitro* is necessary before the genetics of resistance breaking can be determined. (Jones.)

Pea-root eelworm (Heterodera göttingiana)

Attempts to induce the hatch and emergence of larvae from cysts continued. Subjecting the cysts to various temperature and moisture regimes after extracting them from soil and before putting them to hatch in diffusate had no effect, nor did changing the relative concentrations of oxygen and carbon dioxide. The possibility that pea-root diffusate is unstable was considered in another experiment in which diffusate, freshly produced by leaching germinating peas with distilled water, was added to cysts three times daily, but it did not stimulate hatching. Culture filtrates of six of the most prevalent rhizosphere fungi associated with peas added to cysts in pea-root diffusate and in water likewise gave no hatch.

Experiments in sand with various moisture contents gave a

maximum emergence of 2% in the presence of peas. Comparable tests with beet eelworm and rape plants gave a maximum emergence of 50%, but of the few pea-root eelworm larvae that hatched, far more succeeded in invading the roots of the host plant. In a plot of peas infested with pea-root eelworm the maximum emergence in weekly soil samplings was 8% of the eggs within cysts, which suggests that the rate of hatching in the field is also low, but more work is necessary to confirm this. (Shepherd.)

Other work in progress on cyst-nematodes includes population studies on potato-root eelworm, cereal-root eelworm and pea-root eelworm. (Doncaster, Hesling and Shepherd.)

Chrysanthemum Eelworm *Aphelenchoides ritzema bosi*

Work was started on chrysanthemum eelworm, and a simple technique devised for infecting plants with known numbers of worms. Cuttings of the variety Orange Peach Blossom disinfested by hot-water treatment were infested with eight inoculum levels ranging from 15 to 400 eelworms/cutting in ninefold replication. As the inoculum level rose, the number of plants showing symptoms and the severity of the symptoms increased. At 400 eelworms/cutting the mean height of the plants was only 46% of the controls. In a trial of 13 chrysanthemum varieties, 15 disinfested cuttings of each variety were inoculated with about 100 eelworms each. Five cuttings of each variety were left uninoculated as controls. Varietal differences in susceptibility and in the expression of symptoms were observed, and all reported symptoms were produced on one variety or another (blind plants, plants with distorted or needle-like leaves, etc.). Sections cut through infested leaves showed that the nematodes invade the palisade tissue as well as the mesophyll. The most obvious symptom was the disappearance of chloroplasts when the nematodes began to feed.

Soil from beneath heavily infested chrysanthemums was divided into two portions, one of which was sterilized, and both were stored in bunkers during winter. All chrysanthemum plants grown in both soils in the following year grew well and showed no symptoms, which suggests that the eelworm cannot overwinter without weeds. Spread of the eelworm from plant to plant by leaf contact or through the soil was slight, but during the year the soil population immediately beneath infested plants increased and reached a level of about 50–100 eelworms/100 ml. of soil in late October.

Infesting the surface of single, rooted leaves produced definite and consistent varietal reactions. Some varieties turn brown within 2 days whereas others show little or no discoloration for more than 8 days. The eelworm does not multiply in rapidly browning tissue, which is the reaction of resistant varieties in the field and may be regarded as a form of hypersensitivity to feeding. Varieties that show little or no browning are susceptible in the field, and the eelworm multiplies on them. (Hesling and Wallace.)

Parasitism in Aseptic Plant Tissue Cultures

Dr. L. R. Krusberg, a visiting worker from the United States, successfully cultured *Ditylenchus dipsaci* and *Aphelenchoides rit-*

zema bosi on lucerne seedling and callus tissue grown aseptically on nutrient agar. *Meloidogyne incognita* also reproduced on roots of tomato and lucerne seedlings in culture but not on callus tissue. Although lucerne is not a host of *Pratylenchus zeae*, this nematode will reproduce on lucerne callus in the presence of coconut milk. With 15% of coconut milk in the medium 30,000 nematodes were extracted from $\frac{1}{2}$ g. of callus (fresh weight) 6 months after inoculation with 50 worms. So some substance or substances in coconut milk enable the nematode to grow and reproduce on lucerne callus.

The gross character and the histopathology of galls caused by *D. dipsaci* on Du Puits lucerne seedlings grown in soil or aseptically on nutrient agar are essentially the same. Infected shoot apices exhibiting cortical and pith infections are very similar. Externally they appear puffy, and internally they have enlarged and collapsed cells, cavities filled with nematodes and eggs, and the cytoplasm and nuclei are distorted. Infected tissues a few mm. below the apex are not swollen or distorted, although cavities formed by the nematodes contain many worms and eggs. A few cells near the cavities are distorted, but there is no galling or cell enlargement such as occurs at the apex.

Callus formed from the hypocotyls of lucerne seedlings under the influence of 2:4-D provided "ready made" galls and resembled the cortical tissues in old infected shoot apices of plants growing in the field. Nematodes occurred in groups in cavities within the callus and scattered between its loose parenchymatous cells. Infected callus 20 days after inoculation looked similar to uninfected callus except for the cavities containing nematodes.

Tests on extracts from lucerne tissues grown in the field, from seedlings and callus grown aseptically on nutrient agar, and from the medium upon which plant tissues had been grown, showed no qualitative effects on sugars, but there were differences in amino-acids and organic acids between non-infected plants and plants infected with *D. dipsaci*. The components separated on the paper chromatograms have not yet been completely identified.

Soil Conditions Affecting Hatch and Movement of Nematodes

Further studies of larval emergence from cysts were undertaken to test previous hypotheses in more detail. Using sand at various suctions, the peak emergence corresponded roughly to the point on the moisture characteristic where little water remained in the pores. The results confirmed that the optimum suction for emergence was related to particle size but also indicated that, at the optimum suction, the rate of emergence decreased with particle size. Contrary to previous suggestions, there does not appear to be a limiting suction for emergence. Results when the medium in which the hatching tests were done was changed at different intervals of time suggest that carbon dioxide accumulates in the vicinity of cysts and inhibits further hatch. Larval emergence from cysts after hatching is probably governed by the same factors that affect movement through soil.

The optimum crumb sizes for the movement of potato-root eel-

worm larvae through sandy loam, heavy clay and peat soils all lay between 150 and 400 μ diameter. There was little difference in mobility in sandy loam or clay. In peat, however, mobility increased with suction and was still increasing at the highest suction used, so that the optimum suction was not established. This suggests that the larvae can move in relatively dry peat. In a moisture gradient in sand, larvae tended to move to the wet end. The rate of spread of larvae in sand with particles from 150 and 250 μ diameter varied between 2 and 3 cm. a day, depending on suction. The relationship between the cross-section of the larval body and pore size appears to be important in deciding whether the larvae respond to a moisture gradient. Direct observations on larvae newly emerged from cysts in the presence of host roots suggest that larvae orientate themselves at a distance from the root and do not reach the root by random movement. (Wallace.)

Nematicides

Work on nematicides was re-started. Various methods of applying nematicides in the field and in the laboratory were tested, and methods of assessing kill were explored. Silver compounds, iodine, chlorophenols, cresol, hydroxy-benzoic acids and Gentian violet showed some nematicidal activity towards chrysanthemum eelworm (*Aphelenchoides ritzema bosi*). Caprylic and pelargonic acids were so phytotoxic that their activity was not tested. (Peachey.)

Trials with nematicides were made on a carrot crop at the Royal Horticultural Society's Gardens at Wisley. In the soil at this site carrots suffer from an undetermined " sickness ", which may or may not be associated with the nematode population of the soil (*Pratylenchus penetrans* and other Tylenchida). " Vapam " and methyl bromide gave excellent control of plant parasitic nematodes at planting time. Populations were still very low after harvest on the " Vapam " plots, but had risen on the methyl bromide plots. Ethylene dibromide, " VC13 " and dichloro diethyl ether were less effective. The best carrot yield followed treatment with methyl bromide. Yields from " Vapam " and " VC13 " plots were about equal, although the latter gave only a poor control of nematodes. (Peachey and Winslow.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

Dr. Frederick Tattersfield, founder of the department and the friend of many of its present members, died on 1 May 1959. His death was a great personal loss.

J. Ward left to join Mitchell Cotts and Co. Ltd. Mr. Jose Maria Rey, of Instituto de Edafologia y Fisiologia Vegetal of Spain, and Mr. Talip Öden, of Institute of Plant Protection Chemicals and Equipment, Ankara, Turkey, arrived to work in the department.

At the request of Dr. Rasmussen, K. A. Lord was seconded for biochemical work at the Institute of Plant Systematics and Genetics, Royal Agricultural College of Sweden, on strains of insect resistant to insecticides.

The Analytical Methods Committee of the Society of Analytical Chemistry has retained P. H. Needham to advise and report on the use of bioassay methods for the detection and estimation of pesticide residues in foodstuffs. At the request of the committee he visited laboratories working on this subject in the United Kingdom and several other European countries.

At the invitation of the Ministry of Agriculture, Fisheries and Food C. Potter attended the International Conference on the use of Aviation in Agriculture at Bedford and read a paper on the effect of aerial spraying on wild life.

At the request of Dr. T. F. West of the African Pyrethrum Technical Information Centre Ltd., M. Elliott accompanied him to the works of Messrs. George Scott and Sons Ltd., Leven, Fife, Scotland, and those of Messrs. Leybold Hochvakuum Anlagen G.m.b.H., Germany, to advise at work's scale trials on the molecular distillation of pyrethrum extract.

The new departmental glasshouse was completed and is in full use. Progress was made with the three constant environment rooms, but it seems unlikely they will be completed for some months.

Insecticides

Action of organo-phosphorus insecticides

Insect eggs. A possible reason for the embryo of *Pieris brassicae* L. completing its development after an early application of a lethal dose of TEPP would be that the poison is stored in the shell or extra-embryonic membranes and does not reach the embryo until after resorption, when the embryo attempts to eat its way out. Although considered improbable, because TEPP is unstable and so unlikely to remain active in the shell for several days, the idea was tested. The choria and membranes were dissected off poisoned and unpoisoned eggs in the last stages of development, both before and after resorption of the outer membranes. The percentage survival of dissected and undissected eggs was similar, which indicates that the deaths at the end of development were not caused by poison stored in the chorion and membranes. (Molloy.)

The purification and properties of esterases of eggs of *Pieris brassicae* L. were further studied. The purification procedure for removing natural inhibitor from new-laid eggs was improved to give an almost inhibitor-free brei, which can be freeze-dried without loss of activity. Preliminary tests indicated that little or no esterase was adsorbed on a polyurethane sponge, so this material was used for electrophoresis of the brei of eggs from 0 to 12 hours old. The patterns obtained can best be explained by the presence of at least three esterases responsible for the hydrolysis of the four substrates used, which were the phenyl esters of acetic, propionic, butyric and caproic acids. A proportion of the acetic and propionic acid esters are hydrolysed by esterase resistant to inhibition by $10^{-4}M$ paraoxon. This concentration of paraoxon inhibited hydrolysis of the butyric and caproic acid esters. Preliminary tests indicate that $10^{-4}M$ eserine inhibits hydrolysis of phenyl acetate but not the hydrolysis of the other three substrates. The more sensitive method of assay used in these tests showed that the breis from 0–12-hour-old eggs slowly hydrolysed phenyl laurate and phenyl stearate.

Paper electrophoresis of purified breis of 5-day-old eggs (incubation period $5\frac{1}{2}$–6 days) gave results best explained by the presence of at least five distinct esterases hydrolysing the four phenyl esters studied. As with the 0–12-hour-old eggs, the hydrolysis of the butyric and caproic acid esters was strongly inhibited by $10^{-4}M$ paraoxon, whereas hydrolysis of the acetic and butyric acid esters was much less inhibited. (Solly.)

Histochemical studies on the action of organo-phosphorus insecticides

Normal flies. Work continued on the effect on the cholinesterases of the central nervous system when houseflies are poisoned by diazinon (O, O-diethyl O-(2-*iso*propyl-6-methyl-4-pyrimidyl thiophosphate). The Koelle technique was used to detect the cholinesterase in whole mounts and frozen sections of the ganglia of treated and untreated insects.

Inhibition of cholinesterases after poisoning with diazinon is most obvious in the thoracic ganglionic mass (i.e., fused thoracic and abdominal ganglia). With an LD/50 dose, there was little inhibition in the thoracic ganglia shortly after poisoning, but inhibition gradually increased with time and was progressive from the outer peripheral region of the ganglia inwards. At a higher concentration, e.g., LD/95, peripheral inhibition appeared within 2–4 hours of poisoning and was complete throughout the ganglia at 24 hours. The condition of the fly at a given time after poisoning, e.g., slightly, or badly affected or moribund, was reflected in the amount of visible inhibition in the thoracic ganglion mass. For instance, a slightly or badly affected fly generally lacks cholinesterase in the sheath and nerves arising from the ganglia, and to a greater or lesser extent in the cortical region immediately beneath the sheath. The interior part of the ganglia or neuropile may still contain considerable amounts of enzyme. A sharp and darkly staining line of demarcation often occurs between the inner enzymic zone and the zone of inhibition at the periphery. A moribund or dead fly may lack cholinesterase completely, or the enzyme may be confined to the central part of the ganglionic mass only.

There was rarely any inhibition of cholinesterase in sections of the brain after poisoning, even in dead flies, unless very heavy doses were used, when there was sometimes general inhibition throughout the brain.

The 1-μl. drop of poison was usually applied to the ventral part of the thorax, near the thoracic ganglia, and this could have made the local concentration of poison large enough to swamp the enzyme. However, experiments in which the poison was applied to the dorsal thorax and ventral abdomen showed that the amount of enzyme in the thoracic ganglionic mass was related to the state of the individual fly after poisoning and was irrespective of the site of application of the poison. The poison was not applied to the head, because 50% of acetone-treated controls died when the drop was placed close to the head or mouth parts.

If inhibition of cholinesterase of the nervous system causes death these results suggest that the inhibition occurs predominantly in the thoracic ganglia and not in the cerebral ganglia, which might have been assumed to be the more critical sites. (Molloy.)

Comparison between normal and resistant flies. With the techniques mentioned above, the effect of diazinon on the cholinesterases of the central nervous system of normal and a diazinon-resistant strain of houseflies was compared. A discriminating dose of 0·04% diazinon, which killed 90% of the susceptible strain and less than 5% of the resistant strain, was first used. After 18 hours most of the susceptible flies were dead or dying, and histochemical examination showed that cholinesterase was inhibited in the thoracic ganglia but not in the brain. Most of the resistant flies then seemed unaffected or only slightly affected, and these showed no inhibition or very slight inhibition in the ganglionic sheath only.

After a 100% lethal dose, i.e., 0·4% diazinon on the susceptible flies and 1·0% on the resistant flies, the cholinesterase was almost completely inhibited in both strains in the thoracic ganglia, and very slightly inhibited in the brain. In this experiment the flies were probably grossly overdosed, so the significance of this correlation between death and the inhibition of the cholinesterase of the thoracic ganglia is being further studied. (Molloy.)

The inheritance of resistance to organo-phosphorus compounds

In continued selection and bioassays on diazinon-resistant strains of houseflies, *Musca domestica* L., both the selected and unselected series of the Sacca and Keiding 203a strains maintained their resistance levels—the Sacca selected strain at 10× and the unselected at 4× the normal level, the Keiding 203a at 20× and the unselected at 2·5× the normal level. A cross between the two selected strains (203a × Sacca) resulted in a strain of higher and still increasing resistance; when last measured it was approximately 40× the normal.

A strain of housefly very susceptible to diazinon was obtained in January 1959 from Holland by the courtesy of Dr. Van Asperen of Utrecht University. It is being kept for biological and biochemical comparisons with the resistant strains, and for the genetical analysis.

Breeding experiments on the inheritance of resistance, done in

collaboration with Dr. H. Kalmus of the Galton Laboratory, University College, London, showed that mass crosses between the resistant 203a strain and the susceptible Dutch strain gave offspring with resistance intermediate between that of the parent strains. This could be explained by resistance to diazinon being controlled either by one intermediate gene or by many genes. To decide between these alternatives, further population tests and single pair matings are being made. (Kruggel and Piall.)

Toxicity and persistence of insecticidal deposits

The factors influencing the toxicity of residual films were further studied and the toxicity was assessed by the thermal-preference technique with houseflies as test subjects and a 5 minutes' exposure time. Experiments on how age affects the toxicity of residual films of DDT showed that deposits from DDT–xylene emulsion on wax-coated glass plates increased their toxicity after 2 days, whereas DDT–xylene–liquid paraffin solutions applied in the same way did not. Suspensions of 60-μ needles of DDT deposited on glass plates increased in toxicity after 16 days. Coumarone resin or aluminium monostearate added to DDT–xylene emulsions in amounts equal to $\frac{1}{10}$ the DDT content, gave deposits on glass which were two to four times as toxic as those from plain emulsion, but the two formulations had similar toxicities when applied to a cabbage leaf. Adding large amounts of Arochlor resin lowered the toxicity of deposits from the emulsion on leaves. (Ward and Gillham.)

Pyrethrins and related compounds

Molecular distillation of the pyrethrins. The possibility of separating the insecticidal esters in pyrethrum extract from inert and coloured materials was studied, using a laboratory 2-inch wiped film molecular still. The conditions for obtaining a pale-coloured distillate containing 60–70% of pyrethrins, together with some waxes and other inert materials, were determined. The undistilled residue contains less than 10% pyrethrins; no thermally isomerised pyrethrins I and II (see *Rep. Rothamst. exp. Sta.* for 1957, p. 137; 1958, p. 121) can be detected. This work was done in collaboration with Mr. J. S. Olejniczak (Messrs. Edwards High Vacuum Ltd.) and Mr. J. J. Garner (Messrs. George Scott and Sons (London) Ltd.). (Elliott.)

Isolation of cinerolone from pyrethrum extract. When pyrethrolone is separated from cinerolone by recrystallisation of its hydrate from ether the more soluble cinerolone hydrate is concentrated in the mother liquors and is difficult to separate and purify. It was found that (+)-cinerolone acetate, free from (+)-pyrethrolone acetate (as shown by ultraviolet and infrared spectra, by refractive index and by analysis) can be obtained by fractionally distilling the mixture through a column packed with stainless-steel gauze rings; this selectively polymerises and holds back the pyrethrolone acetate. Thus (+)-cinerolone, like (+)-pyrethrolone, can now be isolated fairly easily from pyrethrum extract to use in reconstituting pure cinerins I and II. The cinerolone acetate so obtained appears homogeneous, and the analytical results exclude the possibility that keto-alcohols, difficult to detect otherwise and related to cinerolone

but with singly unsaturated five carbon side chains, occur combined in the extract. (Elliott.)

Characterisation of Pyrethrins I and II as 2 : 4-Dinitrophenylhydrazones. Pyrethrin I with 2 : 4-dinitrophenylhydrazine in methanolic sulphuric acid gives the expected phenylhydrazone of the intact ester. However, pyrethrin II, under the same conditions, gives a mixture of pyrethrin II–2 : 4-dinitrophenylhydrazone and appreciable quantities of pyrethrolone methyl ether 2 : 4-dinitrophenylhydrazone. The required derivative of pyrethrin II is difficult to separate from this mixture, but it can be obtained by another method in which an ether-*iso*-octane solution of pyrethrin II is treated with aqueous 2 : 4-dinitrophenylhydrazine sulphate for some weeks. The greater tendency of pyrethrin II to be cleaved must be caused by the methoxycarbonyl group in pyrethrin II transmitting its effect along the double bond and *cyclo*propane ring of the acid, so making the link to pyrethrolone weaker than in pyrethrin I. (Elliott.)

Biological activity of pyrethrum constituents. The biological activity of reconstituted and naturally derived constituents of commercial pyrethrum extracts were studied on reconstituted constituents prepared by Elliott, and on chromatographed extracts provided by Dr. Thain of the Tropical Products Institute. Five- to six-day-old female houseflies were treated topically with a 1-μl. drop of solution in acetone, kept at 20° C. after treatment and examined 24 hours later for mortality. The relative toxicity of the four constituents at the LD50 level was: Commercial pyrethrum extract 1·0, pyrethrin II 1·5, pyrethrin I 1·0, cinerin II 0·5–0·6, cinerin I 0·4–0·5. The probit lines for the extract and the two pyrethrins had steeper slopes than those of the two cinerins. The reconstituted materials and those obtained by chromatographic separation behaved similarly.

The concentration of the individual constituents of the standard commercial pyrethrum extract were determined chromatographically by Dr. Thain. As the LD50's of the standard and its constituents were also known, the theoretical LD25, 50 and 75 of the extract could be determined in terms of pyrethrin I equivalents. The theoretical and experimental results agreed well, which suggests that the constituents of the extract are neither antagonistic nor synergistic but act in a simple additive manner. This suggestion was supported by making mixtures of pyrethrin I and cinerin I, and pyrethrin II and cinerin II and estimating their toxicity.

Preliminary results with methyl cellosolve as solvent indicate that in this medium pyrethrins I and II are equitoxic and are about 1·5 times more active than the standard. This and other results (*Rep. Rothamst. exp. Sta.* for 1957, p. 140) make it probable that the relative toxicities are not constant for a species of insect, and vary with the technique and solvent used. (Sawicki, Thain and Elliott.)

The biological examination of a commercial pyrethrum extract, chromatographed by Dr. Thain of the Tropical Products Institute, showed that the activity was restricted to the four known active constituents. The sweet-smelling substances coming in front of cinerin I and pyrethrin I, and the pyrethroid coming after pyrethrin II, were biologically inactive. Solutions containing the four pure

constituents in the same concentrations as in three commercial extracts had the same toxicities as the extracts, so commercial pyrethrum extracts are unlikely to contain insecticidal substances other than the four known ones. (Sawicki and Thain.)

Analysis of γ-BHC in soil

The technique of estimation of γ-BHC in soil was further studied. Cold extraction with solvents did not give satisfactory results when insecticides had been in contact with the soil for any length of time, and hot acetone extracted much interfering matter together with the γ-BHC. The method finally used involved refluxing the soil with 50% aqueous acetone. Nitration of the residue obtained from the soil extract (1958 Report) was the most satisfactory method for removing interfering substances. Some of the nitro compounds formed in this reaction interfered with the final colour test, and the nitrated residue had to be reduced with titanous chloride, because the action of zinc and acid in the next stage, i.e., reduction of γ-BHC, was not sufficient. The Schechter and Hornstein method, involving reduction of the BHC to benzene by zinc powder in glacial acetic acid was therefore modified, and the reduction done in aqueous hydrochloric acid, with zinc amalgam, using the Hancock and Laws apparatus. The benzene was swept into nitrating acid by the hydrogen also evolved. The final colour development was based on that used by Schechter and Hornstein. By this method, recoveries of 90% were obtained. The method as modified was used in the range of 0–10 μg., based on *m*-dinitro-benzene produced in the final nitration, and the blanks were brought to between 0·5 and 1 μg., that is 4–7 μg. on 100 g. soil. (Ward and Jeffs.)

Fifty soil samples from the National Vegetable Research Station, Wellesbourne, were analysed for γ-BHC by this method, which completed the experiment on taint started in 1955 under the auspices of the Agricultural Improvement Council. The samples from the 1955 plots taken in autumn 1957 still contained some γ-BHC, but had lost about 80% of the amount applied. The 1956 Wellesbourne plots show a loss of 75–80% by autumn 1957, and the 1956 Fen soil plots, highly organic soil, showed a loss of 40–60% by autumn 1957. (Jeffs and Gillham.)

Uptake of aldrin and dieldrin in wheat seedlings

As part of a study on how aldrin and dieldrin applied as seed-dressings, kill wheat-bulb-fly larvae, the uptake of these materials from dressed seed was measured. Using materials labelled with radioactive chlorine, 3 μl. of an approximately 50% solution of each insecticide in dioxan was applied directly to the seed, mostly on the embryo. The insecticides tended to crystallize out on the seed, so a second experiment was done, using a 50% solution in dioxan and " Tween 80 ", when no crystals formed. The treated seeds were germinated in silver sand at 10° C., and after periods of 30–40 days the young plants were dissected into coleoptile, shoot (growing point and leaf base, excluding coleoptile) and leaves. The coleoptile was rinsed with acetone to remove surface-adhering insecticide. The separate parts were then extracted, and the residual radioactivity in each part measured with a scintillation counter. The coleoptile

contained 5–23 p.p.m. of dieldrin, the shoot, 4–10 p.p.m. and the leaves, 1–3 p.p.m.

An experiment on the solubilities of aldrin and dieldrin in water suggested that the aldrin preparation used contained a water-soluble radioactive impurity; the results obtained for aldrin are therefore not reported. (Jeffs, Ward and Way.)

Insect rearing

The following insects were reared in the department during the year:

Plant Feeding

Hemiptera	*Megoura viciae* Buck.
	Aphis fabae Scop.
	Acyrthosiphon pisum Harris.
	Rhopalosiphum padi (L.)
Lepidoptera	*Pieris brassicae* L.
	Diataraxia oleracea L.
Coleoptera	*Phaedon cochleariae* F.
Diptera	*Leptohylemyia coarctata* Fall.

Stored product, domestic and medical

Orthoptera	*Blatella germanica* L.
	Blatta orientalis L.
	Periplaneta americana L.
	Gryllus domesticus L.
Coleoptera	*Oryzaephilus surinamensis* L.
	Oryzaephilus mercator Four.
	Tribolium castaneum Hbst.
	Tribolium confusum Duval.
	Tenebrio molitor L.
	Trogoderma granarium Everts.
Diptera	*Aëdes aegypti* L.
	Drosophila melanogaster Meig.
	Musca domestica L.

Bioassay techniques

A technique for the knockdown assessment of topically treated normally active houseflies. A vacuum technique enabled houseflies to be immobilised, sexed, dosed and the knockdown effect assessed within 15 minutes or less after dosing. Techniques in which the insects are anaesthetised or chilled to immobilise them are thought not to assess knockdown reliably. The flies were sucked in batches from a modified fly cage on to a terylene gauze attached to a suction platform on the hose of a vacuum cleaner. The insects were not affected by suction, and when the number dosed was between 8 and 10, the dosing time difference was small. Drops of 0·125 µl. or smaller had to be used to prevent them from being sucked off the fly by air flow. The fate of the dose under the airflow conditions of test was studied under ultraviolet light using acetone, cellosolve

and odourless kerosene containing fluorescent dyes. Kerosene spread very rapidly over the body of the insects; the other solvents evaporated rapidly. This technique has been devised to test the knockdown activity of the constituents of pyrethrum. (Sawicki.)

Technique of microbioassay with larvae of Aëdes aegypti

The bioassay technique used to detect insecticides in samples of poisoned bees made use of 2nd instar larvae of *Aëdes aegypti*, which were exposed to the purified extract in 2 ml. of water (*Rep. Rothamst. exp. Sta.* for 1957, p. 143) for 2 hours, when the effect on the response of the larvae to light was measured. In the absence of bee extract, a 50% response of a replicate of 15 larvae was obtained to the following quantities of toxicant in 2 ml. of water:

BHC	0·0056 μg.
Dieldrin	0·009 μg.
DDT	0·0072 μg.

Purified bee extract depresses the toxicity of the poison and makes the test less sensitive. With dieldrin, for example, the factor of depression is approximately 4. (Needham.)

Assessment of cholinesterase inhibition in poisoned bees

Methods of detecting organo-phosphorus insecticides were studied in connexion with the work on bee poisoning. Dewaxed extracts of bees suspected of being killed by " Rogor " (*Rep. Rothamst. exp. Sta.* for 1957, p. 143) showed no insecticidal action on larvae of *Aëdes aegypti* and did not inhibit esterase. Extracts of bees killed by topical application of " Rogor " also gave negative results in these tests. Other methods of extracting the poison were tried without success.

Following a suggestion of Dr. Edson of Fison's Pest Control, a different method of detecting organo-phosphorus poisoning was developed. This depended on the amount of esterase inhibition occurring in the insect and not on extracting the poison and measuring its anti-esterase activity *in vitro*. Bees killed by carbon dioxide and ether and stored at 20° C. and 55% R.H. in the dark, retained the cholinesterase (ChE) and phenyl acetate esterase activities in the head (measured by the Warburg technique) for at least 19 days after death, whereas bees killed by topical application to the ventral surface of the thorax of an LD50 of " Rogor " and stored under the same conditions never contained more than 20% of the ChE activity of the controls. The ChE activity in the heads of all the samples of bees received from the National Agricultural Advisory Service (N.A.A.S.) was measured and the samples classified according to their state of preservation. Samples in good condition and with less than 33% of the normal ChE activity were assumed to have been poisoned by an organo-phosphorus or other ChE-inhibiting insecticide.

The occurrence of bee poisoning in the field

Of twenty-nine samples of bees received from Mr. Milne the Chief Bee Advisory Officer of the N.A.A.S., ten contained esterase-

inhibiting material. Judging from the results of the tests and the information received with the samples, it is likely that four contained parathion and six "Rogor". Tests indicated that six further samples contained esterase-inhibiting material, but the decayed state of the bees made the results inconclusive.

Of seven samples containing chlorinated hydrocarbon poisons, three gave positive tests for dieldrin and three for lindane. One contained both DDT and dieldrin. The level of the DDT residue in this sample was only 0·02 μg./bee. Because the LD50 for DDT on bees by topical application is about 9·2 μg./bee and for dieldrin is only 0·15 μg., dieldrin probably caused their death.

One sample contained too few bees for a complete range of tests to be done. Esterase-inhibiting substances were excluded by cholinesterase measurement. A bioassay with mosquito larvae showed the presence of insecticidal substances, probably a chlorinated hydrocarbon, but no test for arsenic was done.

In five samples no insecticide was detected. (Needham and Lolly.)

Bean aphid (Aphis fabae *Scop.*) *control*

Effect of plant density of spring-sown beans on infestation and control. The experiment described on p. 127 of the 1958 Annual Report was repeated and gave the following results:

TABLE 1

Plants per yd. row ...	4·7	9·3	17·2	24·0	36·8	48·4	25·1 *
Yield (cwt./acre) unsprayed	3·0	1·6	2·0	3·4	3·0	5·9	9·2
Sprayed	12·4	17·7	19·8	21·6	23·5	22·5	23·9
Peak aphid Nos. per stem on untreated	4,900	7,800	8,900	4,700	3,100	1,590	680

Row spacing = 22 inches except * = 11 inches.

Big aphid populations developed on all treatments in favourable weather after a large primary migration from the overwintering host. This contrasts with 1958, when initial populations were small and weather unfavourable for aphid development. The following factors are among those influencing the build-up and control of aphids on different densities of crop: amount and time of primary migration, plant height and condition of crop canopy at the time of migration, weather for about 1 month after migration.

Effect of aphicides on beneficial insects. Replicated plots of field beans infested with *Aphis fabae* were sprayed at field strength with different aphicides in 60 gallons water per acre on 6 July and dead aphids and aphid predators collected on sheets placed between the rows of the crop. Stem samples were collected 2 days after spraying and examined in the laboratory for surviving aphids and predators. Surviving predators were also collected by shaking stems over sheets 3 days after spraying. Table 2 shows numbers of dead predators collected on 9-foot lengths of sheet per treatment 1 day after spraying.

TABLE 2

Insecticide	Oz. active ingredient/ acre	Coccinellidae Adults	Coccinellidae Larvae	Syrphid larvae	Anthocoridae
" Phosdrin "	3	7	19	147	3
" Rogor "	6	10	18	171	1
Methyl-demeton (new formulation)	3	3	35	273	1
" P.P. 175 "	3	2	9	297	0
Fluoracetamide... ...	3	3	2	72	1
Untreated (sprayed with wetter)	—	3	1	25	0

Live predators collected 3 days later by " beating " the plants over the same lengths of sheet were:

TABLE 3

	Coccinellidae Adults	Coccinellidae Larvae	Syrphid larvae	Anthocoridae
" Phosdrin "	0	0	1	0
" Rogor "	0	0	0	0
Methyl-demeton ...	9	0	0	0
" P.P. 175 "	1	8	10	3
Fluoroacetamide ...	7	6	14	4
Control	11	19	41	0

The numbers of live predators found on about 100 stems collected from each treatment 2 days after spraying were as follows:

TABLE 4

	Coccinellidae Adults	Coccinellidae Larvae	Syrphidae larvae	Anthocoridae
" Phosdrin "	0	0	1	1
" Rogor "	0	0	0	0
Methyl-demeton ...	1	0	1	0
" P.P. 175 "	5	2	9	1
Fluoroacetamide ...	2	2	47	0
Control	4	5	131	1

No live aphids were found on stem samples from " Phosdrin ", " Rogor " and demeton-methyl-treated plots; 35 and 44 live aphids were counted on fluoroacetamide and " P.P. 175 " samples, and very large numbers on the untreated. All the insecticides, except possibly fluoroacetamide, killed most aphid predators. The results with fluoroacetamide need confirmation because it may act slowly against predators, as it does against aphids.

When honeybees were enclosed in sleeves on stems immediately after spraying and examined 1 day afterwards, fluoroacetamide and " P.P. 175 " seemed less poisonous than the other insecticides, but this needs confirmation.

Natural control in relation to chemical control. Population studies of the active stages of *Aphis fabae* on its overwintering host *Euonymus europaeus* done in collaboration with C. J. Banks of the Entomology Department are now complete, except for further collections of natural enemies. Experiments on overwintering eggs

showed that from 15 to 46% failed to hatch on different *E. europaeus* bushes. Most of these were non-viable, though a few were killed by Anthocorids and incidentally by birds while they were pecking the buds of the host plant, but there was no evidence that birds preyed directly on the eggs in 1958–59.

Big *A. fabae* populations developed in June on the summer hosts *Vicia faba* and *Chenopodium album*, and numbers remained high during July and August. Some predators, notably Coccinellidae, were inexplicably scarce, though Syrphidae became abundant.

Glasshouse experiments confirmed the importance of intraspecific competition in quickly checking the rate *Aphis fabae* multiply early in the development of the population, thereby allowing other factors, such as natural enemies, to overtake the host and check further increase. The results also explain why aphid populations can rise so quickly to their original numbers after inefficient use of insecticides, which may merely decrease numbers to levels where optimum rate of increase is possible. (Way.)

Soil insecticides. The results of an experiment done in 1958 to find whether insecticides applied in the soil affected the spread of aphid-transmitted viruses from infected to healthy potato plants (*Rep. Rothamst. exp. Sta.* for 1958, pp. 128–129), are given on p. 98.

In addition to the chemical assays for insecticide residues in the tubers harvested from this experiment, harvested tubers were planted in pots and kept in a greenhouse at 17°–20° C. until they had produced shoots 1–1½ inches high. Each shoot was then infested with 10 adult apterous *Myzus persicae* and a week later the aphids on the shoots were counted (Table 5). Test 1 began on 14 November 1958 and Test 2 on 3 March 1959.

TABLE 5

M. persicae *found on shoots from daughter tubers 1 week after infestation with 10 adult apterae*

Treatment	Test 1 (13 tubers)		Test 2 (15 tubers)	
	Average No. of aphids per shoot	% untreated	Average No. of aphids per shoot	% untreated
"Thimet", individual doses (1)	56	92	58	95
"Thimet" with fertilizer (2)	40	66	51	84
"Rogor", individual doses (3)	31	51	32	52
Control (4)	61	100	61	100

In both tests insecticide treatments always depressed the aphid populations below the corresponding untreated levels, but the depression was statistically significant only in test 2 with tubers given treatment 3.

The time taken for the shoots to grow to a height of 1 inch was measured and, in test 2, their height when the aphids were counted. (Table 6.)

TABLE 6

	Test 1 (13 tubers)	Test 2 (15 tubers)	
	Average time for growth of shoots to 1 inch (days)	Average time for growth of shoots to 1 inch (days)	Average height at end of test (inches)
" Thimet ", individual doses (1)	66	16·9	4·4
" Thimet " with fertilizer (2)	64	20·3	4·6
" Rogor ", individual doses (3)	64	19·7	2·0
Control (4)	69	12·3	4·7

In test 1 shoots took three to 5·5 times as long as similarly treated shoots in test 2 to grow to a height of 1 inch. In test 1 shoots from tubers given insecticidal treatments took about the same time to reach a height of 1 inch as shoots from untreated tubers, but in test 2 they took from 37 to 60% longer. Treatment 3 decreased the height of the shoots at the end of the test to about one-half that of the untreated ones. Although chemical tests detected little insecticide residue in the tubers, growth was nevertheless abnormal. When such tubers were planted in the field in 1959 the plants from them yielded as well as those from untreated tubers, so effects on young shoots seem not to be reflected in the later growth of the plants.

Several commercial firms showed interest in the work to control potato virus disease by insecticides applied in the soil and made trials with our co-operation. The spraying trials at Efford Horticultural Research Station continued.

Systemic insecticidal seed dressings

Following up the preliminary results reported in 1958, formulation was found to have a considerable effect on the phytotoxicity and on the strength and persistence of the insecticidal effect of seed dressings. The insecticidal activity of foliage of plants grown from seeds of wheat and white mustard dressed with γ-BHC or " Thimet ", was tested with the aphid *Rhopalosiphon padi* for wheat and the beetle *Phaedon cochleariae* for mustard. Formulations used as standards were γ-BHC plus a solution of methyl cellulose which acted as a sticker and " Thimet " plus siliceous earth and methyl cellulose solution. Polyvinyl acetate or methyl cellulose solution plus activated carbon considerably lessened the phytotoxicity of γ-BHC seed-dressings to wheat. Polyethylene glycol and a solution of polyvinyl alcohol had similar but smaller effects. No aphids were killed on wheat by any of the γ-BHC formulations.

γ-BHC dressings in the formulations were not toxic to mustard, but killed beetles fed on the foliage. Judging from the insecticidal activity of the foliage, activated carbon plus methyl cellulose and polyvinyl acetate emulsions slowed the uptake of γ-BHC. Plants grown from seed treated with these materials attained their maximum toxicity slowly and were insecticidal for less time than those given the standard formulation.

" Thimet " formulations containing carbon plus methyl cellulose solution or polyvinyl acetate were less toxic than standard formula-

tions to wheat, but when the ratio of polyvinyl acetate or carbon to " Thimet " was suitable their aphicidal effect persisted much longer. Like γ-BHC, " Thimet " was not toxic to seedlings of mustard, but activated carbon or polyvinyl acetate prolonged the period of insecticidal activity against mustard beetles.

These effects did not happen because the amount of insecticide sticking to the seeds differed with the different formulations, or because the insecticide decomposed at different rates. Activated carbon and polyvinyl acetate probably absorb insecticide and release it slowly, so that it can be taken up by the plant over a long period. Activated carbon and polyvinyl acetate also lowered the toxicity of sodium fluoracetate and pyrolan to wheat. " Aroclor 5460 ", a chlorinated diphenyl resin also released insecticide slowly.

By using a suitable formulation, the rate insecticides are released from a seed-dressing can be greatly affected, with the desirable results of decreasing phytotoxicity and prolonging insecticidal action.

Many field crops are sown at a mean spacing of ½–1½ inches, and when wheat and mustard seeds treated with " Thimet " were sown at these distances, untreated seeds grown in the soil absorbed enough insecticide to become toxic to insects that fed on their foliage. This did not happen at 3 inches spacing. Similar effects were noticed with mustard seed treated with γ-BHC. For unknown reasons, plants from untreated seeds absorbed more insecticide when grown near live treated seeds than when grown near dead treated seeds. (Bardner.)

Seed dressings against wheat-bulb fly (Leptohylemyia coarctata)

Five new compounds were tested as seed-dressings in box tests against wheat-bulb-fly larvae. They were " Sevin ", " Trithion ", dibutyl tin S S′ (bisisoctyl thioglycollate), dibutyl tin di(thiobenzoate) and the new chlorinated hydrocarbon " W.L. 1650 " using a siliceous earth formulation with methyl cellulose solution as a sticker. Only " W.L. 1650 " was as good as heptachlor or dieldrin, which were included in the trial as standards. " Sevin " was very phytotoxic. (Bardner.)

Seed-dressings to control mustard pests

It has been suggested that γ-BHC seed-dressings could control attacks of the stem weevil *Ceuthorrhynchus quadridens* on " Trowse " mustard. Possible seed-dressings for controlling this pest were compared in the glasshouse tests during winter, using the mustard beetle *Phaedon cochleariae* as a test insect. Insecticide was applied at 10% of seed weight, with siliceous earth as a filler. Seeds were sown in potting compost at a rate equivalent to that used in the field. Insecticides tested were γ-BHC, heptachlor, parathion, aldrin, dieldrin, endrin, DDT, " Toxaphene ", " Dipterex ", " Rogor ", " Sevin ", " Thimet " and a new chlorinated hydrocarbon known as " W.L. 1650 ". " Thimet " was the best, killing 84% of beetles caged on foliage for 48 hours. " Rogor " killed 54%, but with the possible exception of γ-BHC, none of the other insecticides had any effect. This test was done 6½ weeks after sowing. Plants were about 2½ inches high and had two pairs of rough leaves. A similar

experiment in summer showed that there was no insecticidal effect with any of the treatments 4 weeks after sowing, when the plants were 6–9 inches high. This lack of persistence of insecticidal effect on rapidly growing plants accounts for the poor results of a small field experiment on stem weevil control. " Thimet " and γ-BHC were tested at three different rates and three sowing dates. Both insecticides protected the seedling for over a month against flea-beetle attack, but did not control stem weevil. A serious attack of *Brevicoryne brassicae* decreased yields of the two later sowings. With the early sowing, the high rate of γ-BHC, applied at 20% of seed weight, gave a significant increase, doubling the yield compared with the control. These experiments show that, although seed dressings may be useful in controlling some mustard pests, they are of little use against stem weevil. (Bardner and Doherty.)

Pests and pollination of brown mustard (Brassica juncea *var.* *" Trowse "*)

Some experiments were done to find whether the Pollen Beetle, *Meligethes aeneus* F., decreases yield of mustard and whether yield could be increased by the pollinating activity of bees when the pollen beetle was not present. In the first, 0, 160, 320 and 480 adult *M. aeneus* were put into cages $5 \times 4 \times 3$ feet, each cage containing 4 mustard plants. The beetles were introduced when the principal racemes of the plant had formed but before flowering had begun. The numbers of flowers, buds, pods set and pods aborted were counted through the season, and a final record was made of the numbers of pods set and aborted and the weight of seed produced when the crop had ripened. The weight of seed in g./plant was:

0 beetles	25·1 g.	± 3·53
160 beetles	18·6 g.	
320 beetles	12·6 g.	
480 beetles	10·9 g.	

Heavy populations of beetles clearly cause much loss of seed, and loss is correlated with the level of infestation. This experiment did not show whether insect pollinators are necessary as agents in increasing the yield; but it showed that a crop could be set in the absence of insects.

In an experiment done in collaboration with the Bee Department, plots of " Trowse " were covered with large cages from which insects were excluded; six cages were used and bees were introduced into half of them and the weight of seed produced at harvest was recorded. Without bees the average yield per plant was 2·14 g. of seed, and with them 2·79 g., an increase not statistically significant. (Doherty.)

Fungicides

Assessment of fungicidal action

The standard method of testing fungicides is to estimate the concentrations necessary to inhibit spore germination. These are, however, not necessarily the minimal concentrations to inhibit infection, because the dose of ultraviolet radiation needed to inhibit infection of broad beans by conidia of *Botrytis* sp. is half that needed

to prevent germination. The relation between germination and infection was therefore studied. Most conidia of our isolate of *Botrytis* retain the ability to germinate until cultures are 50 days old, but lose their ability to infect, when suspended in water, within 20 days. Infectivity of conidia from cultures 20–50 days old was partially restored by adding sucrose, mannose, maltose and honeydew of *Aphis fabae* to the infection drop, but not by amino-acids and vitamins. Lesions were also formed by water suspensions of these old conidia when inoculated to abraded leaves.

Mechanism of action of fungicides

Work began on problems connected with eradicant and protectant properties of fungicides. One of the fungicides of particular interest, triphenyltin acetate, was also used in field trials against potato blight. It greatly decreased the incidence of disease at apparently non-phytotoxic concentrations (0·025 0·15% active material), but the slower rate of defoliation was not reflected in significantly larger yields of tubers. (Last.)

Effect of time of exposure and temperature on the toxicity of fungicides

Work on the effects of time and temperature of exposure on the toxicity of water-soluble fungicides to spores of some strains of *Botrytis fabae* was finished. Spores were kept in solutions of poisons at 10° and 25° C. for about 10 days, during which germination was repeatedly assessed and ED50 values were obtained by conventional methods.

The following summarises the results obtained with twenty poisons, including inorganic metallic salts, organo-mercury compounds, alcohols, phenols, bases and some others.

The difference between the behaviour of different strains of *B. fabae* was one of degree only, but with most strains the effect of temperature on toxicity was quite small; a high sensitivity to temperature was exceptional.

In tests on one typical strain only, all the poisons gave results of the same general pattern. The ED50 increased with the passage of time at each temperature, finally reaching a steady value at the " end-point ". The ED50 was usually greater at 10° C. than at 25° C. throughout the test, and the increase in ED50 was always greater at 10° C. than 25° C. Thus, in the most common case the apparent " temperature coefficient of toxicity " was positive throughout the test; when this was so, it increased in size throughout the test. Less commonly (e.g., phenol, β-picoline), the apparent temperature coefficient was negative when counts were made early in the test, and positive later on.

Poisons whose end-point temperature coefficients were greater than 2·0 when tested on an insensitive strain were: mercuric cyanide (5·1 after 3 days); methyl mercury nitrile (2·2 after 6 days); tertiary butyl alcohol (3·2 after 10 days); phenol (2·6 after 13 days) and pyridine (2·4 after 10 days).

The size of the end-point temperature coefficient bore no relation to the chemical, physical or other biological properties of the poisons used. (McIntosh.)

ENTOMOLOGY DEPARTMENT

K. Mellanby

R. M. Dobson left in December to become lecturer in Agricultural Zoology in Glasgow University; C. A. Edwards was appointed to succeed him, and is expected early in 1960. B. S. Miller left on completing his year's visit, and Jane A. Cochrane moved to Cambridge to continue her work on slugs there in the School of Agriculture. C. J. Banks was seconded for two years to the Central Treaty Organisation Nuclear Centre, Teheran.

C. G. Johnson returned after 2½ years' secondment to the West African Cocoa Research Institute in Ghana. G. W. Heath joined the department in July to work on problems relating to forest soils. D. Calnaido from the Tea Research Institute, Ceylon, a Colombo Plan Scholar, arrived in May, and two Agricultural Research Council scholars, W. S. Tallack and Frances Bull, in the autumn.

The Fauna of the Soil

Work on soil fauna was expanded, and during 1959 several new investigations were started. The name of the department—"Entomology"—has always been interpreted liberally, for not only soil insects but also earthworms, slugs, millipedes, mites and even, at times, moles have been studied. It is more logical to study all the animals living in the soil, for their activities are closely interrelated, than to be restricted by taxonomic exactitude.

Long-term bare fallow plots

Cultivation affects, and usually decreases, the soil fauna. It is sometimes difficult to interpret changes in the fauna, and for that reason studies were begun on what happens when the soil is kept free from plant growth for a long period in the hope of understanding better the changes in fauna with different crops, different forms of cultivation and different manurial regimes.

Two areas at Rothamsted, one of old grassland in Highfield, one of old arable in Fosters, and two at Woburn, one arable plot in Stackyard and one part of the neglected garden near the laboratory, were selected. Three areas are just under ½ acre, and the Woburn garden is ⅛ acre. Soil samples were taken; all areas will be ploughed and cultivated frequently to prevent weed growth. This experiment is planned to continue for 10 years, but progress will be reviewed after 5 years.

Other departments at Rothamsted will co-operate. Chemistry will study changes in organic matter, nitrogen and available nutrients. Physics and Pedology will follow physical changes in soil structure. Microbiology will estimate changes in the microflora. Botany will study the survival of weed seeds, Plant Pathology the changes in the organisms causing crop diseases and Nematology the nematode population. At Woburn fluorine deposition will be

measured. It is intended to try to correlate the changes in fauna with the findings of all these other departments. (Mellanby.)

Rehabilitation of marginal grassland

The experiment at Winder in Lancashire, started in 1954 to study the effect of earthworms in the process of improving hill pasture, continued. The areas which received different manurial treatments, and those to which lead arsenate was applied in 1955 to exclude earthworms, were sampled in the spring and autumn, and earthworms and their egg capsules were counted and identified. No clear-cut effects relating the soil fauna to the herbage have yet been demonstrated.

Various difficulties, inseparable from an experiment several hundred miles from Rothamsted, arise in spite of the valuable co-operation of the farmer on whose land the experiment is situated. It was often difficult to arrange for some treatments to take place on the most desirable date, and to take full advantage of weather conditions. The very dry summer affected growth on all plots, and the " hard grazing " which was intended to play a part in the experiment was impossible before October. There was also an excessive growth of rushes; " spot " spraying with 2–4 D in April was repeated in July with moderate success. (Raw, Dobson and Lofty.)

Rehabilitation of farmland after open-cast coal-mining

Open-cast coal-mining has gone on for some years in Northumberland, near the Cockle Park Experimental Farm of the University of Durham. The top-soil from mined areas was stored separately in heaps for several years while the coal was removed; this affected its structure and fauna. The university Faculty of Agriculture began an experiment comparing various manurial treatments of the restored land with control, undisturbed areas on an adjacent field. At the request of Professor M. M. Cooper the fauna of the restored and control soils were examined before manures, etc., were applied. The control area contained a fairly high (normal) population of earthworms, mites and collembola. The soil of the restored area contained very few animals. These initial observations, and others to be made in the spring of 1960, are meant to serve as a basis for a thorough investigation of the faunal changes, to be made by a worker stationed at Cockle Park but collaborating with Rothamsted. (Mellanby.)

Fauna of Barnfield

Proper sampling to study the soil fauna requires removing large quantities of soil and applying chemicals to expel certain animals, e.g., *Lumbricus terrestris*. For these reasons none of the classical fields has previously been surveyed comprehensively. The decision to stop in 1960 the experiment on Barnfield, where root crops have been grown continuously since 1843, made it possible to sample the fauna in 1959. The mangold sections of the dung, complete fertiliser and no manure plots of series O (no nitrogen), series N (sulphate of ammonia), series A (nitrate of soda) and series AC (nitrate of soda + rape cake) were studied. In August 20 soil samples each $2\frac{1}{2}$ inches diameter and 8 inches deep were taken from each plot to

estimate the arthropod fauna. In October the earthworm population of each plot was estimated by taking 8 soil samples each $8\frac{1}{2}$ inches diameter and 8 inches deep for worms in the top-soil and by treating 10 quadrats each 22 inches square with dilute formalin for worms such as *L. terrestris*, which burrow deeply and cannot be sampled satisfactorily by removing soil samples.

The animals from the samples have not yet all been identified. (Raw and Lofty.)

Earthworm populations in orchards

The amount of leaf litter buried by worms was measured in 5 grass and 2 arable orchards near Wisbech by placing a known number of weighed leaves on the ground beneath wire cages at leaf fall and recording the number and weight of leaves remaining in spring (*Rep. Rothamst. exp. Sta.* for 1958). The leaves which disappeared from the cages were drawn into worm burrows by *Lumbricus terrestris*.

To estimate the earthworm population beneath the cages, potassium permanganate solution was first used, but it underestimated the population greatly. Dilute formalin expelled the worms much more effectively and seemed to give a reliable estimate of *L. terrestris*.

In the grass orchards the number and weight of leaves removed from the cages was closely correlated with the estimated fresh weight of *L. terrestris*. Some orchards had about 20 cwt. of *L. terrestris* per acre, which buried 8–9 cwt (dry wt.) of leaves during the winter. In the arable orchards the removal was more rapid, possibly because the worms had no alternative source of leaf material and the apple leaves were easier to find and pull into burrows when there was no surface vegetation. Evidence to support this was obtained in one grass orchard, where the number of leaves removed from each cage was inversely proportional to the amount of surface vegetation.

Leaves which remained on the soil surface lost about 25% in dry weight between leaf fall and spring.

Adding 10 *L. terrestris* to 2 cages in each orchard increased the leaves removed. This increase was greatest in orchards which already had a high population; this may reflect differences in the survival of the worms added.

Cultivation did not appear to affect the abundance of *L. terrestris* greatly (previous workers showed that the other large earthworms, *Allolobophora longa* and *A. nocturna*, almost disappear when grassland is ploughed); nor did regular applications of farmyard manure or compost. The highest population was recorded in a grass orchard which received an annual dressing of 1 cwt./acre of sulphate of ammonia. The arable orchards contained few *Lumbricus castaneus* or *Allolobophora caliginosa* and no *A. longa* or *A. nocturna*. *L. castaneus* and *A. caliginosa* were most abundant in the two grass orchards where organic manures are applied regularly; *L. castaneus* was particularly abundant in the one getting farmyard manure.

In two grass orchards with a long history of heavy spraying with copper fungicides the only earthworms found were a few *L. castaneus* in the surface litter. In these orchards the leaf litter decomposes slowly on the soil surface and the soil profile has typical

" mor " characteristics. The yield and nutrient status of the trees seems unaffected. (Raw and Lofty.)

Earthworm biology

Four species of worm from Winder (see p. 133 above)—*Lumbricus rubellus*, *Dendrobaena rubida*, *Dendrobaena subrubicunda* and *Eiseniella tetaedra*—were bred in the laboratory, to obtain information on life span and fecundity. (Dobson.)

At Rothamsted a grass field (Pastures) was sampled by digging out a square yard (in four replicates, each 18 inches square) each month. The soil was taken in separate layers, each 3 inches deep, for the first foot from the surface, and lower layers of soil were examined. The results give information on the vertical movements of the different species, the existence of quiescent periods in some and on population dynamics.

Effects of irrigation, to keep the moisture content of the soil at " field capacity ", and of preventing rain falling on the soil, to give dry soil, were studied by sampling as in the grass field.

Nocturnal activity was studied on the surface of a lawn; effects of temperature, water and light were particularly noted. Surface casting on a lawn and a closely-cut area of meadow were followed, and it was attempted to relate the results to temperature and water. Water appears to act in two ways—as soil moisture (measued as pF) and by affecting the humidity in the growing grass. (Gerard, Raw and Mellanby.)

Studies on slugs

Slugs are being increasingly recognised as agricultural pests, which cannot yet be chemically controlled on a field scale. Studies made by Barnes between 1940 and 1949 were revived and extended. Attempts are being made to establish slug cultures in the laboratory, to work out the biology of pest species and to obtain many in a uniform stage of development, which is necessary to evaluate slug poisons. Factors studied include a comparison of containers, of coil cover and the effects of different constant and fluctuating temperatures.

Slug damage to potatoes was studied in a garden where *Arion hortensis* and *Milax budapestensis* occur. The considerable damage to the tubers during the very dry summer of 1959 was surprising, particularly as frequent searches 2 hours after sunset revealed little activity at the soil surface. This showed that underground activity can sometimes contrast sharply with surface activity. The distribution of slugs in the plot and its relation to soil organic matter is being studied. (Stephenson and Barnes.)

Studies relating to forest soil

To obtain information on the rate leaves disappear from the litter layer, small disk samples were taken regularly from labelled leaves lying in Knott Wood (oak and beech) and Geescroft Wilderness (oak only). The samples are weighed and ashed; parallel samples of oak leaf are used in feeding experiments with mites.

Cultures of the mite *Steganacarus magnus* were established to

study feeding and respiration. Respiration is being studied in two types of apparatus, one large enough to hold undisturbed cores of litter and soil up to 7 × 7 mm., the other smaller and suitable for cultures of mites. (Heath.)

Insect Pests of Economic Importance

The department cannot study all pests of agricultural crops, and the programme changes often. Some pests, e.g., gall midges, have been studied intensively and continuously over many years, and work in this group continues. Much attention was paid to aphids in the 1920s, and since the Second World War study of this group has again been an important part of the department's programme. Work on the wheat-bulb fly was intensified in 1953 after severe damage to crops in many parts of Britain. It is now ending, and the results are summarised below (pp. 216–229). Experiments on the farm and in the laboratory with the frit fly, begun in 1957, are being expanded.

Most of the work on pest insects has a double purpose. First, we are concerned with the problems of control, but by biological rather than by chemical methods. Secondly, much of our work concerns principles (e.g., the distribution and spread of insects), and for this economically unimportant insects might equally be used, except that a pest insect is numerous and easily reared and so a good " experimental animal ". We think that work on basic principles may, perhaps unexpectedly, sometimes give information helpful in controlling pests.

Insect pests at Rothamsted

Routine inspections throughout the year were not possible, but whenever suspected pest damage was reported it was investigated. There appeared to be little serious insect damage during 1959, except for that done by bean aphids on an unsprayed field of beans; routine spraying controlled the aphid. Heavy frit-fly attack occurred on late-sown oats (as was intended), but despite this yields of over 30 cwt./acre were obtained. Wheat-bulb fly and bean weevil attack caused little damage. (French.)

Gall midges

The long-term study of the Wheat Blossom Midges on Broadbalk reached its 33rd consecutive year. A new record for longevity of *S. mosellana* larvae was established; one midge emerged on 23 June 1959 from a larva collected in late July 1941.

Last year's study of the field susceptibility of Atle, Svenno and Fylgia to Wheat Blossom Midges' attack was extended to certain American varieties of known resistance or susceptibility to Hessian Fly in America. Only one of the varieties was resistant to *Sitodiplosis mosellana* and none to *Contarinia tritici*. When tested with Hessian Fly of mixed foreign parentage, the susceptible variety Tenmarq was attacked and the resistant varieties were not.

Advantage was taken of the dry harvest this year to repeat last year's investigation with Dr. P. Halton at the Cereals Research Station, St. Albans, into the damage done by *Sitodiplosis mosellana*

(not *Contarinia tritici* as erroneously stated in last year's report) to wheat grains, as this effects milling and baking quality. Three hard red winter wheats differing in their resistance to attack by Hessian Fly (*Mayetiola destructor* Say) were compared at the fourth leaf stage for their content of constituents soluble in 80% ethanol as a preliminary attempt to find any biochemical basis for resistance. This work was done with the co-operation of Dr. T. Swain at the Low Temperature Research Station, Cambridge. The main difference was that the susceptible variety (Tenmarq) contained allulose, or allulose combined with some other component, whereas the resistant variety C.I. 12855 did not, and the semi-resistant Ponca contained less than did Tenmarq. Tenmarq but not the other varieties also contain Sorbitol. It is, of course, not known whether these differences are connected with differences in susceptibility.

Further data were collected on the speed at which the life cycle of the Hessian Fly is completed in an open unheated glasshouse, and the work on how humidity and temperature affect the speed and percentage of emergence of the Hessian Fly's overwintering larvae was published.

Evidence of delayed emergence was obtained in preliminary studies of the phenology of the Pea Midge, *Contarinia pisi*. More midges that had completed their larval feeding in the field during 1957 emerged in the Rothamsted Lodge insectary in 1959 than in 1958. There was evidence that the Pea Midge produces unisexual families.

The species of grass-inhabiting *Mayetiola* reported in last year's Report as damaging cocksfoot was identified as *M. dactylidis*. Mr. R. Gair of the National Agricultural Advisory Service reported an outbreak of a *Mayetiola* species on *Poa* near Newark, Notts, in the late autumn of 1958. This midge was reared and identified as *M. schoberi*, discovered in Germany in 1957. Midges were reared for the first time from *Mayetiola* larvae damaging *Agrostis*. An undescribed *Mayetiola* species on *Festuca* and already known to occur in England was received from Denmark.

Mr. K. M. Harris, while on a visit from Nigeria, prepared for publication a description of a new sorghum stem midge. (Barnes, Arnold and Miller.)

Aphids

Work on aphids and their distribution has, for some years, included a wide range of subjects difficult to classify briefly. A detailed study of the many insects accumulated over the past years continues and is making it possible to formulate general principles of insect dispersal. Work on aphid physiology and control continued.

The collections of insects, and of biological and meteorological data obtained during several years at Cardington (where traps were operated at different altitudes) are being sorted and arranged for a general study of the vertical profile of insect density, applying to many orders, in relation to time of day, time of year and atmospheric conditions. The factors operating in the mass migration of aphids were found to apply to migrant insects of other orders, and a

general system of insect mass migration is being developed. (Johnson.)

The distribution of small insects, once they have " taken off ", is primarily determined by wind, for the wind speed, except very close to vegetation, is usually greater than their flight speed (e.g., under 2 miles per hour for aphids). Suction-trap experiments show that larger insects, including some species of moths, are distributed differently. These larger insects fly at speeds above the average wind speeds and so determine their own distribution to a considerable extent. (Taylor.)

Aphids may take a series of short flights, and they may probe plants on which they land after each of these flights, but they do not readily settle down to reproduce until they have been airborne for some time. Mass flights of aphids at low levels were observed; the insects frequently alight and take off again, but only when the air is stable, mainly in the evening and in autumn. This behaviour, possible only under these atmospheric conditions, may well favour virus transmission. Usually the wind speed is greater than the flight speed of aphids, so the insects may be carried high into the air and may remain there, flying, for long periods. Laboratory experiments suggest that insects flown to exhaustion do not take off again when they land, but settle down and form colonies, a conclusion supported by the fact that small colonies examined on beans usually still contain winged parents. It is suggested that high-level dispersion spreads populations efficiently, because when after a long flight an alate aphid finds a plant it is likely to stay on it and reproduce. (Taylor and Cockbain.)

A major factor on the infestation of crops by aphids seems to be the filtering effect of the crop on the wind; and aphids probably can alight only when wind eddies carry them into the crop shelter. (Taylor and Cockbain.)

The anomalous behaviour of an aphid, closely allied to *A. fabae*, in selecting a host was studied. This aphid, which breeds in summer on Tropaeolum, will readily fly to and settle down to feed and reproduce on broad beans. In a few days the parent, and any nymphs that may have been produced, die. Yet neither walks off the plant. The aphids received no sap from the plants; how their pattern of behaviour has become so maladjusted to their ability to feed is not known. (Taylor.)

Some workers have considered that many of the insects found in summer at high altitudes are unimportant because they are likely to be dead or so damaged that they cannot reproduce when they land. In joint work with Mr. W. G. Harper of the Meteorological Office on the cause of radar " angels ", insects were caught in nets at Cardington between 1,000 and 5,000 feet above the ground. They were nearly all alive and active. Many of the insects, mainly aphids, but also including frit flies and a fly indistinguishable from the Hessian Fly, were viable, fertile and produced live eggs or young when placed on suitable host plants. This confirms that many small day-flying insects can easily and safely circulate up to several thousand feet before being deposited, unharmed, on a plant. (Taylor.)

The flight physiology of *Aphis fabae* and the effects of prolonged flight on vitality were studied. The aphids use most of their carbo-

hydrate reserve in the first hour of flight, but then use fat, sometimes for flights lasting as long as 12 hours. Flight fatigue seems to result mainly or entirely from exhaustion of fuel, and not from dehydration, neural fatigue or the accumulation of waste metabolites. Provided they found food, aphids flown to exhaustion lived as long and reproduced as successfully as those that flew for only 15 minutes. Aphids flown to exhaustion, however, could seldom be induced to fly on the following day (though they had fed amply), whereas aphids that had flown for only 15 minutes flew again readily. (Cockbain.)

Work on natural control in relation to chemical control was continued by Banks in collaboration with M. J. Way of the Insecticides Department (pp. 126–127).

Eggs of certain predators of aphids, particularly Coccinellidae and Syrphidae, were attacked by ants, but the stalked eggs of Chrysopidae seemed to escape. (Banks.)

Effects of the nature of the food on the biology of *Aphis fabae* were studied. Many alatae were produced on mature bean leaves for three generations after the first, but few alatae occurred on young bean growth. The results suggest that the quality of the sap ingested by the aphids is more important in wing-determination than its quantity and that some results previously attributed to ant attendance require to be reassessed. The results also show that form determination in *Aphis fabae* can occur after birth instead of before birth, as happens in some other aphid species. An attempt to study reproduction and the rate of development on different varieties of beans, " resistant " and " susceptible " to aphids, failed because many aphids died from the heat in the summer of 1959. (Banks.)

Wheat-bulb fly

The predators and parasites of wheat-bulb fly were studied briefly. Pupae obtained from Broadbalk in 1958 were kept in soil pots in the insectary and examined periodically. Many individuals of the cynipoid parasite *Trybliographa* sp. were obtained. A few of these emerged during the autumn of 1958, but most during a few days in March 1959. The insects were sent to Mr. G. J. Kerrich of the Commonwealth Institute of Entomology for further study and specific identification.

Some 4,000 pupae obtained from Whittlesea and Peterborough (Fenland) were kept (mostly) individually and examined daily. 3,431 wheat-bulb flies emerged and 257 specimens of *Aleochara bipustulata*, 105 specimens of *A. inconspicua* Auhe (Staphylinidae—parasitic forms) and 2 specimens of the Ichneumonoid *Phrygadeuon trichops* Thoms. were obtained. Ninety-eight other pupae had evidently been parasitised—possibly by *Aleochora* sp. The two species of *Aleochora* differ biologically—*A. bipustulata* pupates inside the host puparium while the smaller *A. inconspicua* pupates in a small cell in the soil. Various soil arthropods were also found to attack the eggs and puparia. (Dobson.)

Of another 3,275 pupae obtained from the field, 2,045 emerged successfully; 533 of the failures (16·3% of all pupae) appeared to be

parasitised. The mean weight of pupae was 11·4 mg., with a range of 5–17 mg. The mean weight of the sexes did not differ, and under constant temperature flies emerged earlier from smaller pupae. (Long.)

The very wet autumn of 1958 delayed sowing of winter wheat, which was not completed on Broadbalk until January 1959. Large areas of Section V (first year after fallow) were water-logged for much of the winter, germination was poor and the plant density was about half that expected. Wheat-bulb-fly eggs had already started to hatch when the wheat germinated, so there were no plants for the larvae to parasitise and they died. The infestation by wheat-bulb fly was therefore small; the estimated mean population of 55,000 larvae/acre was little more than one-tenth of that in 1958. On the Alternate Wheat and Fallow experiment, where sowing was completed earlier, germination was also not good, but plants were in the single leaf stage (i.e., they could be attacked) at the time of hatching, and the infestation (184,000 larvae/acre) was comparable with that of 1958. In wheat sown at normal density in this experiment 75% of the larvae died for in the first two of its three instars. (Long.)

The interaction between larva and plant is being analysed in collaboration with M. G. Morris of the Statistics Department. An improved sampling technique was devised, and 630 samples, each equivalent to a 1-foot row of wheat sown at normal density, were examined from the Alternate Wheat and Fallow on Hoosfield. (Long.)

Previous observations showed that in different years, and on different sites, the size of mature larvae varied considerably. A study of the effect of size on fecundity showed that smaller flies lay fewer eggs. Thus, factors governing larval size may influence the size of the next generation, and the possibility is being tested of forecasting from observations on larval infestation and associated factors both the immediate effect on the crop and the trend of the population.

Numerous flies were dissected and examined for fungal parasitism, but very few flies were infected; possibly because of the dry summer, only one contained a cystic fungus, which did not grow in culture. (Long.)

Frit fly

Several experiments with frit fly in oat crops were done at Rothamsted. Results in 1958 showed that this insect may behave differently in small plots and in fields uniformly planted with the same crop, so for most of the experiments areas of $\frac{1}{2}$ acre or more were used.

On Long Hoos V an experiment—planned to provide information that may help in forecasting frit-fly attack, so that advice on spraying with insecticides can be given as early as possible—was made in collaboration with Mr. A. H. Strickland and Mr. K. S. George of the Ministry of Agriculture, Fisheries and Food Plant Pathology Laboratory. An area of about 3 acres was divided into 6 blocks and sown with the oat variety Blenda. The area was split

into 2 randomised blocks of 2 plots, and 2 replicates were sown on each of 3 dates, i.e., 13 March, 10 April and 22 May. Frit fly were caught by nets and traps throughout the season, and the eggs laid, tillers attacked and grains attacked were measured. The results are being compared with those of similar experiments in other parts of England.

On Little Knott I an area of about 4 acres was sown with oats on 11 April, half with the variety Eagle and half with Sun II. The migration of frit fly into the different parts of the field was estimated by "sticky traps" which were examined every day from the beginning of May (when the flies first emerged) until the flies disappeared several weeks after harvest. Part of the field received two sprays of DDT, part was caged during the early weeks of growth to prevent tiller attack, and part was sprayed with the weed-killer CMPP. Egg laying, tiller and grain attack were measured for different parts of the field. The rate of infestation in 1959 was rather low, though up to a third of the plants eventually suffered tiller attack, and the dry weather enabled a crop, unusually heavy for such late sowing, of over 30 cwt/acre, to be harvested. (Mellanby, French and Riches.)

Experiments on small plots of oats on various parts of the farm were compared with the field-scale tests. R. Hull arranged for a small area of oats to be sown at Dunholme Field Station, and for tiller and grain samples from this plot and from a commercial field of oats nearby to be sent to Rothamsted for examination. On the Garden Plots detailed studies on the infestation of the grain and of the date of panicle burst were made. Unfortunately birds damaged many marked panicles, but enough material for several months' work was obtained. Bulking samples of panicles which burst between 22 June and 14 July, with the variety Eagle 57% of main grain and 29% of bosom grains were attacked. The comparable figures for Sun II were 46 and 24%. (Riches, French and Mellanby.)

An intensive trapping programme was begun in June to study the behaviour of the frit fly and the effects of climatic and microclimatic changes. This included placing traps in a tower up to 60 feet above the ground, in clearings of different sizes in the oat crop and in different crops in various parts of the farm. Other insects are being included in this work, particularly during the winter, when threshold temperatures for the appearance of several species are being studied. (Calnaido and Mellanby.)

A suitable method of breeding frit flies during the winter months was found, based on the work of Mr. A. Ibbotson of Durham University, and modifications which may increase the size of the culture population are being tested. An olfactometer, designed to offer to frit fly and other insects repeated choices between air and odour streams, is being made; it is hoped to use this to study the rôle of olfactory stimuli in the selection of oviposition sites. (Bull and Mellanby.)

Mite Ecology and Physiology

Although mites form an important part of the soil fauna, particularly in forest soils, they have received little attention. The

ecology of a sphagnum bog near Woburn was selected for their study because conditions are thought to be less complicated than in soil, but similar principles may apply. Eighteen random samples of cores of 9 cm. diameter were taken each month from each of two apparently homogeneous areas of two species of sphagnum in a transitional valley bog. The animals in these samples were extracted by a modified Tullgren funnel, and changes in population throughout the year estimated. These population changes are being correlated with climatic changes. Temperature, humidity and evaporation were recorded at regular intervals within the sphagnum, at different levels above ground and in other types of vegetation over continuous periods of 24 hours; this should make it possible to interpret the effects within the vegetation of conditions recorded by the traditional meteorological techniques.

Laboratory experiments were done on the effects of temperature and humidity on various species of mites, some from the sphagnum and others from drier environments. Apparatus was made to study the behaviour of mites in gradients of temperature and humidity and their survival under different climatic conditions. Great differences of behaviour between hygrophyl, mesophyl and xerophyl species were observed. (Madge and Mellanby.)

Migration of Lepidoptera

Records of migrating butterflies and moths are regularly received from some eighty observers throughout the British Isles, who fill up a form and return it twice a year. Records are abstracted from entomological publications, and many other reports of insect movements of special interest are also received. This provides a picture covering the whole country.

In spite of the hot, dry summer of 1959, migrants were not abundant. The only apparent effect of the weather was to increase their number in September, a time when the number usually begins to fall. The species which showed this most were the Red Admiral (*Vanessa atalanta*), the Silver Y Moth (*Plusia gamma*), the Rush Veneer Moth (*Nomophila noctuella*) and the Humming-bird Hawk Moth (*Macroglossa stellatarum*). The Clouded Yellow (*Colias crocea*) was also common in August and September in the south of England and Ireland, and isolated individuals were captured as far north as southern Scotland. Other regular migrants were rare, particularly the Painted Lady (*Vanessa cardui*).

The Cabbage White Butterfly (*Pieris brassicae*) was abundant in some places during the spring, almost certainly because pupae overwintered, for there was no evidence of an immigration at this, or any other, time. During the summer it was rare and the caterpillar caused little damage. (French.)

Biology of Sciomyzidae

Professor C. O. Berg of Cornell University visited the department during a European tour to study Sciomyzidae (Diptera) parasitic upon land snails. Sciomyzid flies (often called " Marsh Flies ") were found on the dry chalk slopes of Ivinghoe beacon and

in swamps by the River Ver. In the Nature Conservancy reserve at Wood Walton, Hunts, eggs of the Sciomyzid *Pherbellia schoenherri* were found on the shells of Succineid snails. Most of the life cycle of the fly has been worked out from material brought back to Rothamsted. (Stephenson with Professor C. O. Berg, Cornell University.)

Spider Ecology

The importance of predation by spiders in various habitats is being studied. In the laboratory, physiological experiments on food consumption by spiders began. (Tallack and Mellanby.)

BEE DEPARTMENT

C. G. Butler

In September J. B. Free returned from Ontario Agricultural College, where he studied pollination problems for a year, and S. C. Jay, of the University of Manitoba, arrived to work on the nutritional and other requirements of the honeybee larva.

J. Simpson attended the foundation meeting of the European Committée of the Bee Research Association in Paris.

Members of the Department again lectured to scientific societies, beekeepers' associations, etc., and served on various committees.

Bee Behaviour

Swarming

The conclusion that swarm preparations are less frequent in colonies with queens reared in the current year than in those with queens of the previous year (Simpson, *J. agric. Sci.* **49** (1957), 387–393) was confirmed by analysing records kindly supplied by Mr. R. O. B. Manley, for these showed that colonies with 2-year-old queens prepared to swarm more than three times as often as did those with 1-year-old queens. (Simpson.)

Mated laying queens of colonies not rearing queens contain about four times as much queen substance as do either mated laying queens of swarms from uncrowded colonies or superseded queens, and queen rearing during swarming and supersedure preparations in uncrowded colonies probably results from insufficient queen substance. The amount of queen substance produced during a queen's laying life probably gradually decreases until it is too little to inhibit her colony from rearing queens. However, queens made to swarm by overcrowding colonies contain as much queen substance as do mated laying queens from colonies not rearing queens. Workers of colonies preparing to swarm have the same requirements for queen substance as have workers from colonies not preparing to swarm, so queen rearing in overcrowded colonies probably results from ineffective distribution of queen substance rather than from the queen producing too little. (Butler.)

In 1952 Simpson made a large colony swarm, when it only had one queen cell (containing an egg), by overcrowding it, and in 1959 he similarly made a small colony swarm without any accompanying queen rearing. Thus crowding can induce swarm emergence without queen rearing being an intermediate stage. Such swarming approaches the type called " absconding ", which is frequent with *Apis indica* but rare with *Apis mellifera*, in which *all* the bees leave their hive during unfavourable conditions without the colony reproducing.

Although queen rearing is always regulated by amount of queen substance, it is uncertain whether the shortage of queen substance leading to queen rearing in an uncrowded colony preparatory to swarming results from swarm preparations somehow changing the

queen's production of queen substance, or whether the queen-substance deficiency initiates the swarm preparations. Experiments to discover whether an uncrowded colony that is rearing queens can be prevented from swarming by giving extra queen substance must wait until the substance is plentiful. An active fraction of queen substance was isolated in a crystalline form and partly identified (Butler, Callow and Johnston, *Nature* **184** (1959), p. 1871), and it is hoped that this will lead to its synthesis and tests of its applications in practical beekeeping.

Swarms were found to contain many bees that remembered the position of their parent colony and some that did not. When orientated bees were released a short distance from their swarm they returned to the site of their parent colony, demonstrating that swarming had neither obliterated their memory of the old site nor irreversibly changed their behaviour. Bees of a swarm hived a short distance from its parent colony do not return to the latter (unless their queen is taken away), but this is not because they have forgotten it. (Simpson.)

Queen balling

Worker bees sometimes surround a queen to form a " ball ". Such behaviour can result in the queen's death, but does not always do so, and it is often stated that there are two kinds of " balls ". We have now established this and found that in one kind the workers are aggressive and kill the queen, whereas in the other they " protect " her. Hostile balls were produced by removing queens from their colonies and returning them about 5 hours later or, in susceptible colonies, merely by introducing an alien odour, such as that of marked young bees or smoke. In these balls the workers tightly gripped the queen and other bees with their mandibles, vibrated their wings, produced high-pitched buzzing sounds and curved their abdomens round as though attempting to sting. The bees often lost their grip on the comb and the ball fell slowly to the hive floor, where the queen was killed. Benign balls occurred around virgin queens which had accidentally escaped from their cells. These balls were looser and did not fall from the comb. The workers forming such a ball did not buzz or vibrate their wings but licked at the queen herself and even at the place where she had touched the glass of the observation hive. The queen frequently escaped from these balls and appeared unhurt. The balls were similar to, but larger than, the clusters of bees which had previously prevented the queen from leaving their cells. (Simpson.)

Gland development and bee behaviour

About the time that worker bees begin foraging their hypopharyngeal glands retrogress, but redevelop should they need to feed brood. This was shown by capturing foragers at the hive entrance, confining them in groups in cages at 35° C. and giving them pollen-candy and water. When larvae were also present in a cage, and only then, the bees' hypopharyngeal glands redeveloped, showing that the protein (pollen) diet alone did not stimulate the glands but that larvae also needed to be present. (Free and Spencer-Booth.)

How diet during the first week of adult life affects the develop-

ment of a worker's hypopharyngeal glands and its subsequent behaviour was studied. Newly emerged bees were divided into three groups. Two groups were caged in the hive, where one was fed on carbohydrate only, and the other on carbohydrate and protein (pollen); the third (control) group was left free in the hive. All the caged bees were released in the hive when 8 days old. The group fed on carbohydrate only began foraging earlier than the other two and, unlike the other two, the hypopharyngeal glands of this group never developed sufficiently for them to be likely to secrete brood food. Probably, therefore, these bees started foraging earlier because they omitted brood feeding from the normal sequence of duties. There was little difference in development or behaviour in the other two groups. (Free.)

Previous workers have found differences between the food given to young and old worker larvae. This could mean that the food given and the age of larvae fed changes as a nurse bee gets older. However, observations on the distribution of bees of known age on combs containing larvae of different ages showed that bees of each age were almost equally distributed on these combs irrespective of the age of the larvae. Therefore, it is likely that an individual bee varies the composition of the food to suit the age of the larva it is feeding. (Free.)

Drifting

Experiments to determine the way in which bees distinguish their own hives from those of other colonies were continued. Painting a square foot of each hive immediately above its entrance a distinguishing colour is about as effective in preventing drifting as is painting the entire hives different colours. Bees also learn something of the shapes of their hives because they drift more frequently to hives with the same number of brood chambers as their own than to hives of different shapes and sizes. (Free and Spencer-Booth.)

Temporary acceptance of larvae in queen cells by queenright colonies

At weekly intervals during the summer of 1957 ten young worker larvae, placed in artificial queen-cell cups in a frame as for queen rearing, were put between combs of young brood in apparently normal colonies without removing their mated laying queens or isolating them. Whenever a colony began to rear queens spontaneously it was discarded from the experiment. Thirteen colonies remained in the experiment continuously for 16 weeks; between 2 and 10 of them temporarily accepted 3–23% of the larvae in the queen cell cups in the various weeks. When the accepted larvae were left in the colonies, however, they were rejected after a few days. The number of larvae accepted varied significantly from week to week and colony to colony; one group of colonies, headed by queens bred from stock received from the U.S.S.R., was particularly inclined to accept larvae. No connexion could be shown between acceptance of larvae and weather, colony size or subsequent spontaneous rearing of queens. Larvae were accepted in February and April, and it is uncertain whether they are less readily accepted in winter than in summer. (Butler and Simpson.)

General Research

Mandibular glands of workers

The food of honeybee larvae contains a substantial amount of 10-hydroxy-Δ^2-decenoic acid. (Butenandt and Rembold, *Hoppe-Seyl. Z.* **308** (1957), 284.) Having studied the properties of the secretions of the various salivary glands of adult workers, Simpson (see publications) concluded that their mandibular glands were the most likely source of this substance. Glands were supplied to Dr. S. A. Barker and his colleagues at Birmingham University and to Dr. R. K. Callow and Miss N. C. Johnston of the National Institute for Medical Research, who previously isolated the principal component of mandibular gland secretion from an extract of worker bees' heads. Both groups independently confirmed the presence of 10-hydroxy-Δ^2-decenoic acid in the mandibular glands. Its occurrence as the main constituent of the secretion was shown by Dr. Callow and Miss Johnston, and its absence from the other salivary glands by Dr. Barker and his colleagues.

Male genitalia of Apis *species*

During attempts to obtain semen from *A. indica* drones to inseminate *A. mellifera* queens, important anatomical differences between the male genitalia of these two species were noted. These differences may prevent normal hybridisation. (Simpson.)

Queen substance production by virgin queens

Virgin queens sometimes fail to prevent even small colonies from rearing queens because they do not produce enough queen substance. This makes it difficult to replace the virgin queen of a colony by a mated laying queen, because when there is a low level of queen substance among workers it is difficult to make them accept a mated laying queen. (Butler.)

Wax extraction

Various methods of extracting beeswax from old brood combs were tested, but with the best tried at least 40% of the wax in the comb was lost in the dross. (Fairey.)

Pollination

Although insect pollination is probably necessary for a maximum crop of beans, substantial yields can be obtained without insects; a deficiency of pollination should be suspected when the pods are distributed throughout the length of the stems instead of being mostly at the bottom. (Riedel.)

Experiments of the type previously done with field beans and opium poppies to find the best time to take bees to the crop were extended to peach, sweet cherry, apple, bird's-foot trefoil, lucerne and red clover. The results were all similar and show that delaying taking bees to crops requiring pollination until they have begun to flower always increases the number of foragers, and is particularly beneficial with a crop that has a short flowering period or is less attractive to bees than other flowers in the district. (Free.)

Bee Diseases

European Foul Brood disease

Individually identified larvae that had their food inoculated, when they were less than a day old, with *Streptococcus pluton*, were mostly ejected before they were ready to be sealed in their cells by adult bees. Most ejected larvae were 4–5 days old, but a few became diseased when they were about 5 days old. There was no significant difference in these events when infection was with 100 or 1,000,000 bacterial cells. Many fewer larvae were ejected, and more diseased larvae appeared, when a large proportion of unsealed brood was removed from the colonies at the same time as they were infected, when the colonies were strengthened with adult bees from elsewhere or when the colonies had recently been queenless. Colonies given additional unsealed brood at the same time as they were infected removed more infected and uninfected larvae than usual, but ejected infected larvae preferentially. The cells of infected larvae that pupated successfully were sealed later; the resulting pupae weighed less than normal and voided many viable cells of *S. pluton* in their faeces. The factor underlying all these phenomena seems likely to be nutrition: abundance of larval food leads to pupation of more infected larvae, thus raising the number of cells of *S. pluton* in the colony; shortage of larval food leads to ejection of more infected larvae. Infected larvae that die are presumably in conditions between the two extremes. These events are no doubt connected with the acute annual epidemic of disease at the end of June in endemically infected colonies.

The few larvae less than 2 days old that pupated after infection left a faecal deposit rich in *S. pluton* in the form of lanceolate cocci in their cells. The larger number of survivors of larvae, infected with the same dose when 2 days old, left few bacteria, most of which appeared rod-like and reminiscent of *S. pluton* grown *in vitro* in the presence of oxygen.

Larvae were ejected as described above when inoculation was with *S. pluton* cultivated *in vitro*; *S. pluton* grown in the presence of 5% air was significantly less virulent (measured as the percentage of the infected larvae ejected) than when grown anaerobically. (Bailey.)

Diseased larvae contained many more *Bacterium eurydice* than did symptomless larvae from the same colony at the same time; but the incidence of *B. eurydice* did not diminish in healthy larvae until autumn. Although evidence still suggests that this organism facilitates the onset of visible disease in larvae infected with *Streptococcus pluton*, its incidence clearly does not influence natural diminution of European Foul Brood disease, which normally occurs in July. (Bailey and Lee.)

American Foul Brood disease

Individually identified larvae were infected when less than 1 day old with *Bacillus larvae*, as in the experiments described above with *Streptococcus pluton* and at the same time. Some unsealed infected larvae were ejected by the adult bees, but at approximately the same

rate at all ages. The ratio of brood to adult bees seemed to have much less influence on the ejection of larvae infected with *B. larvae* than with *S. pluton*, and larvae that survived were sealed into their cells at the usual age and produced pupae of normal weight. Thus nutrition does not seem to be involved in infection with *B. larvae*: this is not unexpected because very few bacteria develop in infected unsealed larvae. Infected larvae probably become diseased from toxins produced by the few bacteria. The inoculated spores were obtained from the remains of larvae that had died of American Foul Brood disease. Such remains contain water-soluble toxins that could perhaps be a product of larval decomposition, but they did not cause ejection of the larvae in the experiment described, because identical results were produced by both washed and unwashed spores. (Bailey.)

Nosema disease

Infection with *Nosema apis* was more common than usual in England and Wales in the spring of 1959, and many beekeepers suggested that it was responsible for the abnormally heavy winter losses of colonies. However, no significant correlation was obtained when the degree of infection in surviving colonies in the various Rothamsted apiaries in spring was compared with the losses in these apiaries. Furthermore, there was no correlation between the diminution of colonies during the winter and the degree of infection in them in spring. Increased infection was expected after the bad season of 1958, and it undoubtedly contributed to losses, but it seems clear that it was not the general underlying cause. Other effects of a bad season, such as pollen shortage, may be suspected of being responsible.

The effect of increased environmental temperature on the natural incidence of infection in endemically infected colonies was examined. Healthy bees were marked, artificially infected and introduced in mid-summer to endemically infected colonies whose infection had been watched since early spring. After 2 weeks all surviving marked bees were infected and contained as many spores as did naturally infected bees at the height of the spring epidemic. Meanwhile natural infection in the colony continued to diminish as usual. Thus increased environmental temperature does not appear to play a significant part in the natural suppression of infection, as has been claimed elsewhere. (Bailey.)

Acarine disease

Events in 1959 confirmed previous conclusions: the winter mortality of colonies was significantly higher only in the few colonies with over 30 bees infested per cent; by the autumn, infection had fallen to the lowest level since systematic observations of untreated colonies began in 1951, which was expected after the outstandingly good season. Again, as with Nosema disease, there appears to be a positive connexion between heavy infestations and periods of queenlessness or reduced brood rearing. (Bailey.)

Investigations began on the resistance of bees older than about 9 days to infestation with *Acarapis woodi*. Such resistance is widely

attributed to increase in the stiffness of the hairs covering the entrance to the anterior pair of thoracic spiracles in older bees. Accordingly, old and young bees had the hairs shaved off one of their spiracles and were introduced into cages of heavily infested bees. The young bees became infested, with no difference between tracheae leading from shaved or unshaved spiracles, but old bees remained uninfested. Attempts to find the true cause of the resistance continue. (Lee.)

STATISTICS DEPARTMENT

F. YATES

The following members resigned during the year; S. Lipton, on appointment as Senior Lecturer in the School of Mathematics, University of New South Wales, Sydney, for the development of computer work there; O. B. Chedzoy, to Electrical and Musical Industries Ltd.; Edith Avis (Spetch) and Joan Parle (Anderson), on marriage.

New appointments were: G. W. Bonsall, from Armstrong Siddeley Ltd., and C. W. Fearne, from De Havillands Ltd. Seven temporary workers were accommodated during the year, four from overseas.

Yates visited India again at the end of the year on a United Nations Food and Agriculture Organisation assignment to work with the Indian Institute of Agricultural Research Statistics. He also contributed to a conference on mathematics in industry and its relation to mathematical education held at Liverpool University (12.5). Healy is spending a year in the United States at the invitation of Dr. J. W. Tukey of Princeton University. Rees attended the U.N.E.S.C.O. First International Conference on Information Processing in Paris. Church visited Ghana for a joint symposium of the Commission de Cooperation Technique en Afrique au Sud de Sahara and the U.N. Food and Agriculture Organisation, and contributed a paper describing the pilot survey of livestock in Eastern Ethiopia.

THE ELECTRONIC COMPUTER

The electronic computer was very fully used during the year, and continued to give reliable service. In addition to work for Rothamsted, much was done for other research organisations in this country

TABLE 1

Record of machine operation for 1957–59

Percentage of time for:	1957	1958	1959
System modification	0·6	2·4	0·0
Scheduled maintenance	12·4	13·9	9·4
Unscheduled maintenance:			
Computer	6·2	2·3	3·1
Peripheral	1·8	1·5	1·1
Programme checking	17·8	13·3	8·9
Programme tape preparation	4·8	3·5	1·4
Production runs	49·8	58·4	73·9
Abortive efforts:			
Computer	1·3	1·4	0·7
Peripheral	1·0	1·7	0·8
Idle time	4·4	1·7	0·7
Total	100·1	100·1	100·0
Total hours worked	2,622	2,869	2,993
Percentage overtime	32·6%	45·1%	50·8%

and overseas. The machine was operated for a total of 2,993 hours, i.e., 51% in excess of normal laboratory hours, compared with 45% excess in 1958. The longest continuous run was one of 81 hours. Although the total operating time increased by only 4% over 1958, there was a 32% increase in the time devoted to production runs. This reflects the shorter time devoted to maintenance and to programme checking and tape preparation. Details are shown in Table 1.

The output of work per hour of production time also improved through better organisation of machine operations. We now have a very effective team of machine operators.

TABLE 2

Numbers of replicated experiments analysed in the Department

	Number of experiments: By hand	On computer	Total	Number of variates on computer
1934	115	—	115	—
1951	437	—	437	—
1955	384	419	803	834
1956	181	683	864	1,701
1957	98	1,253	1,351	5,041
1958	182	1,664	1,846	6,260
1959	67	2,649	2,716	11,102

The number of replicated experiments analysed on the computer again increased substantially. The number of experiments handled increased by 60% and the number of variate analyses by nearly 80%. Details are shown in Table 2. (Dunwoody, E. P. Simpson, Turner, Gower.) A paper summarising our methods of experimental analysis was presented at a meeting of the German Region of the Biometric Society held in Leipzig (12.13). (Healy.)

The computer was also very fully used for many other types of computation, including the analysis of a number of surveys.

No major modifications were made to the machine, but further tape-handling equipment was acquired and the tape readers were made more reliable. The Hollerith card reader gave good service, and the tape-to-card equipment was also extensively used.

It was decided early in the year to abandon work on the Pye magnetic tape unit, and sanction was obtained to buy a Decca twin magnetic tape unit. This was delivered in December, and work is now proceeding on linking it up with the machine. (Rees and Knight.)

Computers have now been installed in a number of Universities, and are consequently available to university research workers for handling their statistical problems. Before a computer can be effectively used for statistical research, however, an appropriate set of programmes has to be written. To make the experience gained on the Rothamsted 401 computer generally available, a start was made on the construction of a " communication language " suitable for statistical programmes. It is hoped that it will be practicable, without too much labour, to re-write the more important 401 programmes in this language. A trial on the programme for the

analysis of 2^n experiments showed that such re-writing, if done by the author of the original programme, can be effected without much trouble. It also appears that new programmes for the 401 can be conveniently written initially in the communication language and then translated into the 401 order code. (Yates.)

Further experience is required to assess the utility of a communication language of this kind, but should it prove of real value to programmers of other types of machine the re-writing of existing programmes and the writing of new programmes in this language will not only make them available to users of other machines but will also be of great assistance to us when the time comes to replace the 401 with a new machine.

This work is linked with similar work that is now proceeding in many quarters on the evolution of a universal programme language. The philosophy behind such a language is that, for any particular computer, a translation routine or programme can be constructed which will enable the computer to accept programmes written in the universal language, and translate them into the language (i.e. order code) of that computer.

A further piece of similar work was the improvement of the automatic programming routine of the 401, mentioned in the 1956 Rothamsted Report (p. 169), to enable the quantities entering into the computation to be referred to by letter symbols, or a combination of letters and numbers. This simplifies the writing of a programme, and makes the programme, as written, more intelligible, because the algebraic symbols used to state the problem can be written directly in the programme wherever required. The routine was also improved in other ways to make it more convenient for the programmer. (Yates and Bonsall.)

The opportunity was taken, in the course of writing a chapter on the use of electronic computers in survey work for the third edition of *Sampling Methods for Censuses and Surveys*, of working out a general system for the specification of survey analyses (12.1). All the types of analysis that are commonly required can be simply specified in this system, and this in itself will greatly simplify their programming. The ultimate aim is to write an interpretative routine which will interpret these specifications directly, so that no special programming will be required. A full routine of this type will not be practicable for the 401, because of its limited speed and storage capacity, but an attempt will be made to construct a routine which will at least deal with the simpler types of analysis without much special programming. (Yates.)

The problem of handling data from continuous recording apparatus, which concerns many agricultural research institutes, received some preliminary study. The first step is to arrange for the data to be recorded at suitable intervals in digital form so that the record may be fed to the computer without any manual transcription. A specification of suitable equipment for the Glasshouse Crops Research Institute was agreed with a manufacturer. The problem arises in many branches of research and in production control, so it is likely that a number of types of suitable recording instrument will be developed in the near future. A possible alternative solution, which would not involve the installation of special

recording instruments, would be optical scanning of records. (Rees and Gower.)

Experience was also gained in programming the analysis of continuous or quasi-continuous data by the analysis of a series of meteorological observations taken at the Vegetable Research Station, in which the temperature and radiation determinations were obtained from continuous daily records. (Rees.)

Experimental Design and Analysis

The analysis of the 1956–57 results of a set of co-operative fertiliser trials on rice in the State of Bihar, India, referred to in the 1958 Report, was completed successfully and the methods followed were published (12.21). The 1957–58 and 1958–59 results have now been analysed in a similar manner. It is hoped that we shall soon be provided with the results of the 1959–60 experiments, when a combined analysis of the 4 years' results will be undertaken, so that cultivators can be provided with an improved set of recommendations. (Yates, Lipton and Gower.) A similar analysis of a simpler set of fertiliser trials from Pakistan was also made. (Gower.)

The examination of the results of the Rothamsted 1933–58 Three-Course Rotation experiment, on the effects of straw ploughed in or composted, was completed (16). (Patterson.) A brief summary of these results was given in the 1958 Report (p. 167). A paper on the manuring of potatoes, summarising the results of recent factorial fertiliser trials on this crop, was presented to the Society of Chemical Industry. (Boyd.)

We continued to do a great deal of work for the National Agricultural Advisory Service. The electronic computer is now used for the routine analysis of almost all the one-year experiments, and we also handle the results of the long-term experiments and co-operate in the planning of experimental programmes and the design of experiments. (Boyde, Patterson, Lessells and E. P. Simpson.) The results so far obtained from two important series of experiments on the N.A.A.S. Experimental Husbandry Farms, namely the experiments on straw disposal and on residual effects of phosphorus fertilisers, were summarised and a report presented to the Crop Experiments Sub-Committee of the Agricultural Improvement Council. (Patterson.)

Several investigations were made for the Soil Fertility Committee of the Closed Conference of Soil Chemists and some reports prepared. (Lessells.) Work for the National Institute of Agricultural Botany included the examination of the results of the N.A.A.S./N.I.A.B. cereal variety trials and the N.I.A.B. fodder-beet trials. (Boyd and Lessells.)

G. C. Chisci, of the Stazione Sperimentale di Praticoltura, Lodi, Italy, while working in the Department, studied the relative productivity of varieties of lucerne in Northern Italy (12.9), and the value of leaf measurements for discriminating between varieties.

Work for the Advisory Entomologists Conference and the Pest Assessment Committee continued, and a paper was prepared on soil sampling for potato-root eelworm (12.11). (Church.)

Surveys

The analysis of the results of the 1958 Survey of Maincrop Potatoes, made in co-operation with the National Institute of Agricultural Engineering and the Potato Marketing Board, was completed; a report was prepared and will be published shortly. (Church, H. R. Simpson and Hills.)

During 1959 the N.A.A.S. undertook surveys of fertiliser practice in four districts, using a modified sampling and recording technique. The results from these districts and those outstanding from 1958 were analysed. We also analysed the results of similar surveys of fertiliser practice for six districts in Scotland on behalf of the A.R.C. Statistics Unit, Aberdeen. A paper summarising information on recent trends in cereal manuring and describing the methods of fertiliser practice surveys in England and Wales was published (12.10), and also one on survey techniques of interest to the N.A.A.S. (12.8). (Boyd, Church, H. R. Simpson and Hills.)

A pilot survey of herbicide practice was undertaken in conjunction with the A.R.C. Unit of Experimental Agronomy, Oxford, to discover how much information could be obtained on herbicide practice and its effects by interviewing farmers; a paper was prepared describing the results (12.12). Information on the proportions of crop acreages treated with different herbicides was readily obtained, but farmers were usually unable to give details of techniques and times of treatment. The limited information obtainable may, however, be of sufficient value to justify extending this work now that herbicides are so widely used. (Church and Hills.)

The Grassland Survey of England is being analysed on the computer for the Grassland Research Institute. (H. R. Simpson and Mr. C. D. Kemp.)

The results of the First National Survey of Disease in Dairy Cattle covering the year 1957–58 are being analysed on behalf of the Ministry of Agriculture, Fisheries and Food, Animal Health Division, and provisional reports were prepared. This survey follows some pilot surveys of which the results have been published (12.20). Data were obtained from 1,158 farms, and combined techniques involving both the electronic computer and the Hollerith tabulating equipment were used for analysis. This survey provides the first unbiased estimates of the national incidence and relative economic importance of disease in farm animals. The results will be published by H.M.S.O. in the form of a bulletin. A second survey was made during 1958–59. (Leech, H. R. Simpson and Davis.)

The losses of breeding ewes during the 1958–59 breeding season were surveyed by the N.A.A.S. for the Veterinary Investigation Service and will be analysed as soon as complete records have been received. The same flocks will be surveyed in more detail during the current breeding season. (Leech and Davis.)

Plans were worked out in conjunction with the Ministry of Agriculture, Fisheries and Food for a survey of the incidence of *Brucella abortus* infection in dairy cows, which will start in the autumn of 1960. (Leech.)

A study was made by the N.A.A.S. of the effects of various factors on the content in milk of solids other than fat. The data came from

a co-operative investigation on ten farms, seven of which had a history of producing milk low in such solids, and the others were normal farms (12.7). As a result of this work, requests were received to analyse similar sets of data on milk composition from the National Institute for Research in Dairying and the Hannah Dairy Research Institute. These analyses are in progress. Plans were also prepared for the Joint Milk Quality Control Committee for a fuller investigation, and the field work is proceeding. (Leech.)

A report was presented to the Agricultural Research Council's 1959 Conference on Hypomagnesaemia on the incidence of grass tetany estimated from random sample field surveys. (Leech.)

At the request of Dr. K. Rasmussen (Head of the Department of Agricultural Economics, Nottingham University) the relation of gross output of farms to various inputs (fertilisers, labour, etc.) was studied, using 4 years' data on 11 variates for 1,654 English farms and 3 years' data on 13 variates for 1,139 Irish farms. There were over 10,000 cards containing the original data. As a preliminary every variate had to be converted to logarithms, involving 117,197 conversions. Output and the various input factors were found to be very closely related. (Gower.)

Commonwealth Work

We have continued our advisory work for Commonwealth countries and have analysed many experiments on the computer, including a large set of 2^5 manurial trials on a number of crops in Fiji, extensive analyses for the Gambia, maize variety trials for the Maize Rust Research Unit, Nigeria, and experiments of the Tobacco Board, Tanganyika. Advice was given to the Kumasi Technical College, Ghana, on the design of some related long-term experiments on cocoa and to the Nigerian Federal Department of Agricultural Research on the planning of a rotation experiment (with H. Greene). (Vernon.)

Three Commonwealth workers worked in the Department for varying periods.

Other Work

Of the many miscellaneous problems dealt with for various research workers and institutes by members of the Department, the following may be mentioned; most involved the use of the computer:

1. A comparison of various methods advocated for fitting an exponential curve (12.15, 12.17). (Patterson and Lipton.)
2. The development for Dr. C. B. Williams of an asymptotic formula for the remainder terms

$$S(x, R) = \sum_{r=R}^{\infty} \frac{x^r}{r}$$

where $x \sim 1 - 10^{-13}$ and $R \geqslant 10^6$. This formula gives the total number of species in a population with more than R individuals per species. The value of x is related to the possible frequency distribution of number per species for all the insects in the world (10^{18} individuals in 2×10^6 species). (Gower.)

3. A study of the problem of determining the degree of imperfection in mixing batches of seed, for the International Seed Testing Association (12.18). (Westmacott.)

4. Biological studies of the wheat-bulb fly (*Leptohylemyia coarctata* (Fall.)) in conjunction with the Entomology Department. (Dobson, Long and Morris.)

5. The development of a multiple transfer method for plant virus (and other disease) transmission studies, in conjunction with the Plant Pathology Department. (Gibbs and Gower.)

6. Further predator–prey investigations, for Dr. P. H. Leslie of the Bureau of Animal Population, Oxford (12.14). (Gower.)

7. Programming of the Jackson method for the analysis of capture–recapture data, for Mr. J. A. Nelder of the National Vegetable Research Station. This will also be of value for the analysis of similar data being collected by the Rothamsted Entomology Department. (H. R. Simpson.)

8. A study for the Animal Virus Diseases Research Institute, Pirbright, of the efficiency of an approximate method of estimating genetic variance in susceptibility of unweaned mice to foot-and-mouth disease, compared with the maximum likelihood method of estimation. (Leech.)

9. Analysis of comparative ventilation data, for the Glasshouse Crops Research Institute. (Rees and Bonsall.)

10. Further analyses of data from the National Survey of the Health and Development of Children, for the Joint Committee of the Institute of Child Health, Society of Medical Officers of Health and the Population Investigation Committee. (H. R. Simpson.)

11. Studies of growth measurements of children from the Harpenden Survey of the Institute of Child Health. (H. R. Simpson.)

12. A discriminant analysis of data on test reactions for the diagnosis of tuberculosis and leprosy, for the South Metropolitan Cancer Registry. (H. R. Simpson.)

13. Principal component analysis of recidivism data, for Mr. L. T. Wilkins, and prison data for Mr. A. Straker, both of the Home Office. This work was brought to us because of our experience in this type of analysis, after requests were made to several other computer installations. (H. R. Simpson.)

Mr. N. E. G. Gilbert of the John Innes Horticultural Institution continued his work for the Animal Breeding Research Organisation. He also analysed data from the progeny-testing stations of the Pig Industry Development Authority.

H. R. Simpson wrote up his work on the effect of insecticidal applications on tsetse populations (12.22), and Yates contributed a section on methods of sampling human and animal populations to the Report of the World Health Organisation Study Group on Immunological and Haematological Surveys (12.20).

FIELD EXPERIMENTS SECTION

G. V. Dyke

The field experiments at Rothamsted and Woburn are controlled by the Field Plots Committee: F. Yates (Chairman), G. V. Dyke (Secretary), F. C. Bawden, G. W. Cooke, H. V. Garner, P. H. Gregory, J. R. Moffatt, C. A. Thorold, R. G. Warren and D. J. Watson.

On 1 April 1959 H. V. Garner retired from the headship of the Field Experiments Section and was succeeded by G. V. Dyke. H. V. Garner continues to be employed part-time; he spent September in China as one of a small British delegation invited by the Chinese People's Association for Cultural Relations with Foreign Countries.

Table 1 shows the total number of large plots harvested by the staff of the two farms and how they were distributed between different crops and experiments of different types. Two hundred and fifty-three large plots were managed but not harvested by farm staff. In addition, the departments laid down 224 large plots and 392 microplots; the total was 3,170.

Table 1

	Grain	Roots	Hay	Grazing	Total
Classical experiments:					
Rothamsted	230	73	48	—	351
Woburn	52	—	—	—	52
Long-period rotation experiments:					
Rothamsted	263	174	147	96	680
Woburn	157	265	53	12	487
Short-period experiments:					
Rothamsted	404	107	—	—	511
Woburn	147	73	—	—	220
Total	1,253	692	248	108	2,301

Broadbalk

The sowing of Broadbalk was delayed until December by the wet autumn; the condition of the seedbed was the worst for at least 10 years. Sowing was interrupted by bad weather and plot 2 (farmyard manure) was sown 4 weeks after the remainder. Conditions improved and plot 2 made up lost ground, so that by the late winter it looked as well as the rest. Section V (first crop after fallow) became exceptionally weedy as the season advanced, probably because the bare fallow was ineffective in the wet season of 1958. The TCB/MCPA weed-killer applied to section Ia (last fallowed in 1951) checked weeds, and yields generally were close to those of other sections: on the dung plot, however, section Ia yielded much less than the other sections. During the spring and summer plot 16 (minerals and 5 cwt. nitrate of soda) showed exceptionally good colour and growth, and its yield was about 4 cwt./acre higher than plot 7, which receives minerals and an equivalent dressing of sulphate of ammonia.

Broadbalk was harvested early and in excellent condition; there was no lodging. Estimates were made as in 1958 of the amount of chaff, etc., not picked up by the baler. The mean loss, adjusted to 85% dry matter, was 5·7 cwt./acre—rather less than in 1958. Three different sampling methods to determine the proportion of weed seeds and rubbish in the grain delivered by the combine harvester were tested.

Hoosfield Permanent Barley

In April plots receiving nitrate of soda without potash were pale yellow, especially 2AA, which receives also superphosphate, but the colour soon became normal, and no exceptional loss of yield occurred. Yields were above average in spite of the drought. There was an unusually large increase of 2 cwt. grain where silicate of soda was applied.

Spraying was begun as recommended by Dr. E. K. Woodford of the Agricultural Research Council Unit of Experimental Agronomy to control coltsfoot (*Tussilago farfara*). This involves using 2 : 4-D ester on the stubble and MCPA (potassium salt) applied to the crop. First results seemed promising. A few areas were sprayed after harvest with dalapon to control couch grass (*Agropyron repens*).

As in 1958, the plots were harvested by combine-harvester, and on certain plots five separate parallel cuts were made. In some plots in each year the yield from different cuts varied considerably. Although the results for the two seasons are not entirely consistent, the cuts near the edges usually gave higher yields than the inner cuts. This point will be studied on all plots in 1960.

Park Grass

Growth was slow at the beginning of the season on all plots, and the second cut (in mid-September) on some yielded more than the first. In early June the unlimed ends of some plots, especially 10, 11–1 and 11–2, showed scattered patches of bright yellow grass. Yorkshire fog (*Holcus lanatus*), virtually the only species present, was growing nearby quite normally. The yellowing coincided with areas where the peaty mat of partly-decayed grass had come adrift from the true soil below. Normal colour returned after a few weeks.

Just before the first cutting a forage harvester with a flail cutting action was tested on some plots and the samples were compared with those obtained with a normal cutter bar. The flail machine worked well under a wide range of conditions and was used for the whole area at the second cutting. Yields of the second crop were calculated from the fresh weights of sample cuts.

Garden Clover

In July one or two well-grown established plants showed a deformity not previously observed. Each half of each leaflet was rolled downward and inward, the mid-rib remaining almost straight. There was no discoloration. Neighbouring plants seemed quite normal.

Barnfield

In spite of a very dry spell at the time of drilling, a good plant was established on all plots, rather slowly on plots without farmyard manure. The crop later suffered from drought, and wilting was greatest on the well-manured plots where the leaf area was relatively high. Virus yellows was severe; spraying against the aphid vectors was not possible because of the risk that drifting insecticide would affect an adjacent experiment on an insect pest.

Ley–arable experiments

As in recent years, the plots of 3rd-year lucerne were poor, especially on Highfield. Of the two lucerne plots which reached their 3rd year in 1958 one was ploughed up early in that season because of the heavy attack of wilt (*Verticillium*). The wheat grown in 1959 on these two plots differed greatly in the degree of lodging; after 2 years lucerne and a 1-year fallow lodging was severe, but after 3 years lucerne only about 10% of the area was lodged. The yield of grain was higher after the 1 year's fallow.

Combine-Drilling Nitrogen for Spring Cereals

by H. V. Garner

The advantages of combine-drilling phosphorus and potassium fertilisers with the seed of cereals was clearly shown in field experiments during and after the War. The practice was so convenient and successful that it has since become almost standard on the better-equipped corn-growing farms. If nitrogen was put through a combine-drill at all it was in the form of a mixed fertiliser with a strict limit on the maximum content of sulphate of ammonia, usually not more than 0·2 cwt. N/acre. This was quite suitable for winter cereals because most of the nitrogen would not be applied till the spring, but spring cereals presented a problem because the new varieties needed far more than 1 cwt. of sulphate of ammonia/acre, and it would be convenient to apply the whole of the nitrogen through the combine-drill with the phosphate and potash, rather than to go over the ground first with the phosphate and potash and later with the nitrogen. Experiments on spring wheat and barley were therefore made at Rothamsted and Woburn similar to those initiated by G. W. Cooke and F. V. Widdowson in 1954.

The design and rates of dressing were the same for all experiments. A basal dressing of 0·54 cwt. P_2O_5 and 0·54 cwt. K_2O was applied as granular fertiliser by combine-drill. Sulphate of ammonia was applied at four levels (0·00, 0·22, 0·54, and 0·72 cwt. N/acre) either through the combine-drill as part of a granular NPK fertiliser (whose PK provided the basal dressing) or broadcast immediately after sowing the seed. In spite of careful calibration, the scheduled amounts of nutrients could not always be exactly applied, but the discrepancy was seldom large. The broadcast nitrogen was always made equal to the nitrogen drilled. The

granular fertilisers used were 0 : 16 : 16 * at 3·4 cwt.; 5 : 12½ : 12½ at 4·3 cwt.; 8 : 8 : 8 at 6·8 cwt.; and 12 : 9 : 9 at 6·0 cwt./acre.

TABLE 1

Rainfall and cultivations; spring wheat and barley, 1957–59, Rothamsted (R) and Woburn (W)

Centre and Year	*Spring wheat* Sowing date	*Spring wheat* Previous crop	*Barley* Sowing date	*Barley* Previous crop	Rainfall (inches) Oct.–Feb.	Rainfall (inches) March + April	Rainfall (inches) Deviation from mean
R. 1957	2 April	Spring wheat	1 April	Barley	11·18	1·58	−2·25
R. 1958	3 April	Spring wheat	3 April	Spring wheat	13·30	3·11	−0·70
R. 1959	19 March	Winter wheat	19 March	Winter wheat	11·97	5·10	+1·30
W. 1957	—	—	23 March	Potatoes	9·06	1·57	−1·94
W. 1958	11 April	Fallow	3 April	Fallow	11·75	3·07	−0·44
W. 1959	21 March	Spring wheat	20 March	Barley	10·04	4·39	+0·88

At Rothamsted Koga II spring wheat was grown and Herta barley, except in 1959, when it was Proctor. At Woburn the spring wheat was Peko and the barley Herta.

The spring cereals were sown on dates well within the normal range on both farms. In 1957 seedbeds were poor, as the previous winter was free from frost. Germination was uneven and early growth slow. Later the crops were affected by the long spring drought. The crops of 1958 had a much better start, for the spring seedbeds were the best for many years, but from June onwards the weather was dull and wet, with very difficult harvest conditions. In 1959 there was plenty of moisture in the seedbeds and early growth was good; this was followed by a long, bright summer. In all three seasons there were full, even plants, giving low standard errors. Nitrogen effects were very striking. There was no lodging at Rothamsted even in the wet summer of 1958, but at Woburn the heaviest dressings of sulphate of ammonia lodged the barley in 1958. The factor most likely to influence the result of a heavy dose of soluble salts drilled with the seed was the moisture in the soil at sowing and for a few weeks afterwards. The total rainfall for the months of March and April roughly indicate this. There was a big range: in 1957 these months were particularly dry showing a deficit of 2·25 inches at Rothamsted and 1·94 at Woburn; 1958 was near the average; but in 1959 these two spring months were wetter than usual by 1·30 and 0·88 inches respectively. It happened therefore that the manures were tested in dry and in wet springs, and on a heavy and a light soil. The Rothamsted experiments were scored for general appearance when the crops were in full vegetative growth, usually in early June, and again just before harvest. The most obvious effects were responses to nitrogen; the plants without nitrogen were short, thin and pale green; the first level of nitrogen improved growth considerably, but was clearly insufficient, for in all experiments the plots receiving the second level of nitrogen looked still better. In 1959 the plots with the most nitrogen looked by far the best. These early differences persisted till harvest, but on a somewhat reduced scale, and were reflected in the yields.

At Rothamsted also the plots with combine-drilled nitrogen always looked as well and mostly better than those with the same quantity of broadcast nitrogen. At Woburn in 1957, the only year when the observation was made, barley was visibly depressed by the

* The first figure is the percentage of nitrogen (N), the second phosphorus as P_2O_5, the third potassium as K_2O.

heaviest dose of nitrogen combine-drilled. Table 2 shows the effect of increasing doses of nitrogen, averaging both methods of application.

TABLE 2

Spring wheat and barley, responses to nitrogen, Rothamsted (R) and Woburn (W), grain cwt./acre, 1957–59

(Rates of dressing N_1 0·22 cwt., N_2 0·54 cwt., N_3 0·72 cwt./acre. Mean of both methods of application)

Centre and Year	Yield No N	Response to N_1–N_0	N_2–N_1	N_3–N_2
Spring wheat:				
R. 1957	15·1	+5·4	+1·6	0·0
R. 1958	9·9	+5·8	+6·8	−0·8
R. 1959	13·1	+6·3	+6·5	+4·6
Mean	12·7	+5·8	+5·0	+1·3
W. 1958	12·6	+5·0	+1·6	+1·4
W. 1959	9·9	+9·4	+6·0	+2·6
Mean	11·2	+7·2	+3·8	+2·0
Barley:				
R. 1957	20·6	+6·2	+3·8	+1·4
R. 1958	19·0	+6·4	+11·3	+0·1
R. 1959	14·1	+8·0	+9·0	+7·6
Mean	17·9	+6·9	+8·0	+3·0
W. 1957	21·6	+3·1	+6·4	+1·2
W. 1958	20·0	+7·8	+7·4	−1·0
W. 1959	12·7	+10·0	+7·6	+3·9
Mean	18·1	+7·0	+7·1	+1·4

Both crops on both farms responded well to nitrogen. A notable feature was the low yield of spring wheat without nitrogen, only 12 cwt./acre on the average of the 5 experiments; barley grown on the same fields yielded more than the wheat and averaged 18 cwt./acre. The smallest dressing of sulphate of ammonia, 0·22 cwt. N/acre, gave large and approximately equal returns with both cereals, a mean increase of 6·7 cwt. The further response to the second dose of nitrogen was also substantial; the extra 0·32 cwt. N. gave an additional 5·0 cwt. of wheat and 8·0 cwt. barley at Rothamsted, and 3·8 cwt. of wheat and 7·1 cwt. of barley at Woburn. The final increment of 0·18 cwt. N gave much smaller returns, except in 1959, when the responses ranged from 2·6 to 7·6 cwt. grain/acre. Yet even this final 0·18 cwt. N on the average more than paid for its extra cost.

In 1957 and 1958 some of the responses to nitrogen may have reflected the control of take-all, caused by *Ophiobolus graminis*, but there was little of this disease in 1959.

The very large nitrogen effects and the small errors allow the effectiveness of sulphate of ammonia when combine-drilled and when broadcast on the seedbed to be assessed. Table 3 gives the differences between the two for each rate of application.

At Rothamsted combine-drilling sulphate of ammonia gave larger yields of both crops in every year. In 1958 on wheat and in

TABLE 3

Spring wheat and barley, Rothamsted (R) and Woburn (W), 1957–59

(Combine-drilled sulphate of ammonia *minus* broadcast)
Grain (cwt./acre)

	Nitrogen applied (cwt./acre)				Mean of	
	0·22	0·54	0·72	S.E.	all rates	S.E.
Spring wheat:						
R. 1957 ...	+0·7	+1·0	+2·3	1·30	+1·4	0·75
R. 1958 ...	+5·3**	+4·8**	+3·1**	0·65	+4·4**	0·38
R. 1959 ...	+1·2	+0·8	+1·5*	0·64	+1·2**	0·37
Mean ...	+2·4	+2·2	+2·3		+2·3	
W. 1958 ...	−0·3	−5·0**	−2·9**	1·00	−2·8**	0·58
W. 1959 ...	+0·1	−1·1	−0·8	0·92	−0·6	0·53
Mean ...	−0·1	−3·0	−1·8		−1·7	
Barley:						
R. 1957 ...	+1·3	−1·1	+0·1	1·46	+0·1	0·84
R. 1958 ...	+0·8	+1·2	+0·8	1·60	+0·9	0·92
R. 1959 ...	−0·3	+4·4**	+1·8	1·19	+2·0**	0·69
Mean ...	+0·6	+1·5	+0·9		+1·0	
W. 1957 ...	+0·2	−0·9	−3·7*	1·53	−1·4	0·88
W. 1958 ...	+0·3	+2·6	+1·6	1·26	+1·5	0·73
W. 1959 ...	+0·6	+1·8	+3·4*	1·20	+1·9*	0·69
Mean ...	+0·4	+1·2	+0·4		+0·7	

1959 on both crops the advantage from combining the fertiliser was on the average nearly 2·5 cwt. grain/acre and the individual values were statistically significant. In the other three experiments the differences between methods of application were generally small.

At Woburn, where spring wheat was grown in two seasons only, combine-drilling 0·54 cwt. or 0·72 cwt. of N gave lower yields than broadcasting in both years, and in 1958 the difference was highly significant. Barley gave less-consistent results. In the dry seedbeds of 1957 combine drilling at the two higher rates was inferior to broadcasting, but in the conditions of 1958 and 1959 the advantage was with combine drilling. Even when the higher rates were injurious, sulphate of ammonia drilled at 1 cwt./acre was always at least as efficient as when broadcast.

To see whether soluble salt drilled with the seed affected germination and early growth, plants were counted when tillering began. The best determined values were at Rothamsted in 1958 and on both farms in 1959. Seedbeds were fairly moist in both these seasons, and spring rainfall was also up to average. The mean plant population of spring wheat was 1·2 millions/acre; sulphate of ammonia broadcast at any of the three rates lowered the plant number; the mean of all experiments was a 6% decrease below the controls, although the fertiliser more than doubled the yield of grain. Only at Woburn did the population on the drilled and broadcast plots differ significantly. At the highest level of nitrogen the broadcast plots had 27% more plants than the drilled, but the yield difference was only 0·8 cwt. grain/acre. Barley averaged 1·0 million plants/acre; broadcast nitrogen affected plant numbers much less than with wheat. Plant population was not consistently affected by

broadcast nitrogen, and drilled nitrogen was not noticeably harmful; only one big effect was obtained, and this was in favour of drilling.

In 1957, a dry year, plants were counted at Rothamsted. The effects were less well determined than in the other years, but sulphate of ammonia drilled at the highest rate gave fewer wheat plants than when broadcast; on barley, effects were smaller and in favour of drilling.

For both spring wheat and barley at Rothamsted sulphate of ammonia was generally more effective when combine-drilled than when broadcast. At 3½ cwt./acre, the highest rate tested, the mean advantage in favour of combine drilling was +2·3 cwt. of wheat grain and 0·9 cwt of barley, even though the plant populations were sometimes decreased by combine-drilling. At Woburn combine-drilling was less favourable, particularly in the dry year 1957, when the heaviest dressing of drilled nitrogen gave a yield of barley significantly below that given by broadcast nitrogen; in 1958 the same happened with spring wheat. In the wet spring of 1959 barley benefited from drilling even the heaviest dressing of nitrogen. Combine-drilling a small dressing (0·2 cwt. N) was never harmful at Woburn.

Farmyard Manure and its Interactions with Fertilisers

by H. D. Patterson & D. J. Watson

Eight experiments of uniform design were made to measure the responses of crop yield to increasing dressings of farmyard manure and how they depend on fertiliser applications, and from these relationships to assess how far the effects of farmyard manure can be ascribed to the plant nutrients it supplies. Another purpose was to compare the use of farmyard manure on potatoes and sugar beet, so experiments with both crops in the same field were made at Rothamsted and Woburn in 1956 and 1957. The treatments were all combinations of:

Farmyard manure: 0, 5, 10, 20 tons/acre ploughed in during the winter;
N: ammonium sulphate at 0 and 0·9 cwt. N/acre;
P: superphosphate at 0 and 0·75 cwt. P_2O_5/acre;
K: potassium chloride at 0 and 1·5 cwt. K_2O/acre;
and for sugar beet only,
S: agricultural salt at 0 and 5 cwt./acre.

The NPK fertilisers were broadcast in the seedbed and the salt was broadcast some weeks earlier. Each experiment had 4 randomised blocks of 16 plots (i.e., two replicates for potatoes and a single replicate for sugar beet).

Tables 1 and 2 show the mean yields of potatoes and sugar beet over the 2 years and distinguishes between rates of farmyard manure and rates of those fertilisers that were effective. The tables also give responses to manure of 10 tons farmyard manure/acre, averaged over the whole range of rates of application, for each fertiliser treatment.

TABLE 1

Effects of farmyard manure on potatoes

Mean yields of potatoes, 1956–57 (tons/acre)

Fertiliser	Rothamsted Farmyard manure (tons/acre) 0	5	10	20	Mean increase/10 tons farmyard manure/acre
		(±0·44)			(±0·30)
—	9·84	10·74	12·76	13·89	2·10
N	9·96	11·24	12·58	14·24	2·13
P	9·14	11·90	13·11	14·00	2·25
NP	10·94	13·50	14·83	15·20	1·97
K	10·06	11·32	13·42	13·56	1·78
NK	11·20	13·38	13·38	14·12	1·25
PK	12·64	13·77	14·32	15·45	1·35
NPK	13·91	15·02	15·68	15·98	0·98

Fertiliser	Woburn Farmyard manure (tons/acre) 0	5	10	20	
		(±0·46)			(±0·31)
—	9·02	10·24	11·00	13·26	2·08
N	12·64	13·85	14·69	15·26	1·26
K	9·85	9·62	10·98	12·69	1·56
NK	13·98	14·22	14·95	15·16	0·62

Responses to farmyard manure were obtained in all experiments. At Rothamsted potatoes responded to all three main nutrients N, P and K (Table 3). In the same fields no additional sugar was obtained from N applied to sugar beet, but responses to P were unusually large; the main effects of P without farmyard manure were 13·0 cwt. sugar/acre on Great Field II in 1956 and 8·8 cwt. sugar/acre on West Barnfield II in 1957. At Woburn responses to N were large

TABLE 2

Effects of farmyard manure on sugar beet

Mean yields of sugar, 1956–57 (cwt./acre)

Fertiliser	Rothamsted Farmyard manure (tons/acre) 0	5	10	20	Mean increase/10 tons farmyard manure/acre
		(±2·21)			(±1·49)
—	26·7	32·5	39·5	44·3	8·8
P	32·8	40·1	42·9	46·8	6·5
K	30·7	33·8	38·1	42·3	5·9
PK	39·3	44·6	45·7	49·4	4·7
S	30·7	39·0	44·2	44·6	6·5
PS	44·8	45·4	49·7	49·9	2·8
KS	30·3	39·8	43·7	45·6	7·0
PKS	45·2	48·1	46·2	53·0	3·6

Fertiliser	Woburn Farmyard manure (tons/acre) 0	5	10	20	
		(±1·77)			(±1·20)
—	44·3	51·4	51·8	60·8	7·7
N	55·6	56·8	61·7	61·3	3·1
S	47·6	57·8	57·5	59·4	4·9
NS	60·4	62·2	62·3	63·6	1·4

TABLE 3

	Potatoes (tons/acre) Rothamsted	Woburn		Sugar beet (cwt. sugar/ acre) Rothamsted	Woburn
Mean effects of fertilisers in the absence of farmyard manure					
	(±0·31)	(±0·46)		(±1·57)	(±1·78)
N	1·08	3·88	N	−0·8	12·1
P	1·38	0·21	P	10·9	−0·1
K	1·98	1·08	K	2·6	0·8
			S	5·4	4·1
Mean effects on fertiliser responses of 10 tons farmyard manure/acre					
	(±0·21)	(±0·31)		(±1·06)	(±1·19)
N	−0·28	−0·88	N	−0·7	−4·1
P	−0·18	0·18	P	−2·6	−1·2
K	−0·77	−0·58	K	−0·8	−0·3
			S	−1·5	−2·2

in both crops; potatoes also responded to K but not to P. Salt increased yields of sugar at both farms.

In general, responses to fertilisers were decreased by adding farmyard manure (Table 3); decreases were greatest when main effects were greatest.

The large decrease in N response at Woburn, particularly in sugar yield, caused by adding farmyard manure, deserves special mention, because farmyard manure has often been supposed to have little effect on responses to N fertilisers. In this connexion Boyd (1959) * showed that, although responses to N may be unaffected or even increased by applying farmyard manure when P or K is deficient, responses may be decreased when supplies of P and K are adequate. Responses to P and K were relatively small at Woburn, and there is no evidence that lack of either nutrient limited responses to N.

These effects of farmyard manure on responses to fertilisers (and vice-versa, see Tables 1 and 2) are to be expected if farmyard manure acts mainly by supplying the major plant nutrients. As only two levels of each fertiliser were tested and as the experiments were few, the results are inadequate for an independent assessment of the fertiliser equivalents of farmyard manure. They can, however, be used to test the conclusion of Boyd (1959) from work on potatoes, that each 10 tons of farmyard manure effectively equals 0·3 cwt. N, 0·4 cwt. P_2O_5 and 0·75 cwt. K_2O applied as fertiliser. The method of analysis used involved the calculation of multiple regressions on the total effective amounts of nutrients applied to each plot on the hypothesis under test, and is too complicated to describe here.

The results with potatoes support Boyd's hypothesis, but there is an indication that farmyard manure increased the sugar yield of sugar beet more than the suggested fertiliser equivalents. This point can be demonstrated by comparing (*a*) the yields obtained from full fertiliser dressings excluding salt but no farmyard manure, and (*b*) the yields obtained from 20 tons farmyard manure/acre and no fertilisers, in Tables 1 and 2. On the hypothesis under test yield (*b*) should be rather less than (*a*), whereas for sugar (*b*) exceeds (*a*) by about 5 cwt./acre at both farms. Thus the N, P or K equivalents of

* *J. agric. Sci.* **52**, 384–91.

farmyard manure may be greater for sugar beet than for potatoes, but it seems more likely that some other factor is involved. The fact that the effect of salt on sugar beet decreases as more farmyard manure is added may be relevant; the combination of NPK and salt gives as good yields of sugar as does 20 tons farmyard manure/acre. Chemical analyses showed that the farmyard manure contained insufficient sodium to account for the differences between its effects on potatoes and sugar beet.

The conclusion, that farmyard manure is more effective relative to fertilisers for sugar beet than for potatoes, does not of course imply that farmyard manure applied to sugar beet gives a greater economic return than farmyard manure applied to potatoes; this depends on the relative prices of the two crops.

Residual effects

To provide information on the residual effects of farmyard manure each of the experiments was continued for a second year in a barley crop. This received the following fertiliser treatments, combined factorially with the treatments to the previous crop:

N: "Nitro-Chalk" at two levels, 0 and 0·4 cwt. N/acre;

and, after potatoes at Rothamsted only:

P: Superphosphate at two levels, 0 and 0·4 cwt. P_2O_5/acre.

The barley after potatoes at Rothamsted received a basal dressing of 0·8 cwt. K_2O/acre as potassium chloride. In the other experiments in 1957 0·4 cwt. P_2O_5 and 0·2 cwt. K_2O/acre, and in 1958 0·4 cwt. P_2O_5 and 0·4 cwt. K_2O/acre were applied as compound fertilisers.

TABLE 4

Residual Effects

Mean yields of barley (cwt./acre)

Fertilisers *	Farmyard manure to previous potatoes or sugar beet: tons/acre 0	5	10	20	tons/acre 0	5	10	20
	Rothamsted (4 experiments) (±0·40)				Woburn (4 experiments) (±0·82)			
—	33·6	35·4	36·5	37·1	17·6	18·5	20·1	21·7
N_r	36·3	37·0	37·3	38·7	19·7	19·4	20·8	22·1
N	38·0	39·1	38·9	39·9	27·7	26·5	29·0	29·8
N_rN	37·8	38·4	38·4	39·2	27·4	28·7	28·6	29·9
	Rothamsted (2 experiments with sugar beet) (±0·41)							
—	35·5	36·6	36·9	38·2				
P_r	36·6	38·0	38·6	39·5				
	Rothamsted (2 experiments with potatoes) (±0·54)							
—	33·4	35·6	35·8	37·0				
P_r	36·6	37·5	38·0	39·5				
P	37·9	37·8	38·6	38·9				
P_rP	39·4	40·0	38·9	39·2				

* Averages over both levels of all other fertilisers. The suffix r denotes that the N or P was applied to the previous crop.

When no fertilisers were applied to either crop, 20 tons farmyard manure/acre gave residual responses of 3–4 cwt. barley grain/acre (Table 4). These residual effects were, however, smaller when N fertiliser was applied in either year. At Rothamsted applying P fertiliser also decreased the residual effect on barley of farmyard manure applied to potatoes.

These results suggest that farmyard manure can supply both N and P in the year after application; the same may be true of K, but the experiments did not include a test of K fertiliser for barley, nor did K applied to the previous crop affect the barley. The residual effects of farmyard manure are estimated to have been equivalent to about 0·1 cwt. N and 0·15 cwt. P_2O_5/10 tons of farmyard manure/acre.

Ammonium sulphate applied to sugar beet or potatoes given no farmyard manure produced small but definite increases in the yields of the following barley crops both at Rothamsted and Woburn. This is contrary to the commonly held idea that the effects of this fertiliser on annual crops are confined to the year of application, but agrees with recent work of the Chemistry Department (see page 48.) At Rothamsted the residual effects of 0·9 cwt. N/acre were about the same as the effects of 0·1 to 0·15 cwt. N/acre applied directly to the barley. At Woburn the equivalents were much smaller, although the actual effects were about the same because the crops responded much more to N.

The residual effects of ammonium sulphate were decreased by farmyard manure residues or N fertiliser applied to the barley. In the presence of both factors the residual effect was actually negative in the experiments with sugar beet, averaging $-1{\cdot}6 \pm 0{\cdot}4$ cwt. grain/acre over the two highest levels of farmyard manure. No explanation can be offered for this effect, which was not repeated in the experiments with potatoes.

The residues of 0·75 cwt. P_2O_5/acre applied as superphosphate to potatoes at Rothamsted were equivalent to about 0·3 cwt. P_2O_5/acre applied to the barley. This is in accordance with the results of other experiments (see, for example, the summary of the four-course rotation experiment given in *Rep. Rothamst. exp. Sta.* for 1954, p. 153).

Although these experiments agree with the hypothesis that farmyard manure acts mainly by supplying mineral nutrients, a critical test of whether its effect is wholly nutritional would require much more elaborate experiments with many treatments, preferably conducted on soils where substantial effects of organic matter on soil structure are to be expected, and with a number of contrasting crops.

THE FARMS

J. R. Moffatt

Rothamsted

In welcome contrast to 1958, 1959 favoured farm work. The total hours of sunshine for the year were 251 above normal and the rainfall 1·81 inches below normal. The year opened with land work greatly in arrears, but a fine, early spring soon enabled the leeway to be made good. The hot and generally dry summer favoured the corn crops, and the heavy rainfall in July came just in time to save the root crops, which were by then suffering from drought. These crops were lifted in unusually fine weather in autumn, and winter crops were drilled earlier than usual. Wet, mild weather in December delayed field work, but at the end of the year the position was satisfactory.

The Effect of Weather on Crops

The autumn of 1958 was mainly mild and damp, with persistent mist or fog. This, after heavy rain in the late summer, and compaction during harvest, kept the ground wet and intractable. Very little winter corn could be drilled, and what was drilled went in under bad conditions.

Hard frosts alternating with periods of heavy rain throughout January, prevented much field work, but a fine spell during February, when less than $\frac{1}{10}$ inch of rain fell, enabled over 100 acres to be ploughed. The land turned up " livery ", and seedbeds had to be forced. Drilling started early, and by the end of March field work was up to schedule. April weather was favourable, with no cold, drying winds, and spring sowings were completed by the end of the month.

May and June were both dry and warm, and crops made very satisfactory growth. Conditions for haymaking were excellent, although yields were rather light. As the drought intensified, the corn came into ear early and the growth of root crops slowed. Late-planted potatoes suffered more than those planted early; sugar beet and mangolds wilted badly on hot days.

Heavy storms in early July brought 2·83 inches of rain in 2 days, and the monthly total was 4·51 inches, nearly 2 inches above normal. There was some run-off, but most was quickly absorbed by the dry soil; severe but localised lodging of corn resulted. The root crops benefited considerably, but the rain came too late to help the beans, the leaves of which had mostly wilted and dropped off by the end of the month.

Cereal harvest started about 3 weeks earlier than usual, and continued almost uninterrupted to the end. Moisture contents reached a level where drying was unnecessary, but a thunderstorm then raised them to about 20%, and thereafter most grain needed some drying.

September was very dry, with only 0·16 inch of rain. Potato

lifting started towards the end of the month and finished 3 weeks later. During much of the time the lifters were working in a cloud of dust such as is seldom seen.

October and November were dry and conditions for pulling mangolds and lifting sugar beet were excellent, but the root yields were small. In September and October ploughing was difficult because the ground was hard and dry, and it was often burst up rather than ploughed. Seedbeds were obtained only by heavy rollings and disc harrowings; Broadbalk was exceptional, in that it ploughed well and worked down easily. Drilling of winter corn and beans started early and was mostly ended before November. Conditions for ploughing improved during November, and excellent progress was made until the end of the month, when, with only about another week's work remaining, wet weather, which lasted throughout December, prevented any further work.

Field Experiments

The 1958–59 programme of field experiments started badly. One experiment on winter corn had to be abandoned, and one was postponed until spring; sowing dates on other experiments were determined by the condition of the land rather than the requirements of the experimenter. Broadbalk wheat field was drilled early in December, except for the plot receiving dung. The onset of thick fog prevented this plot being drilled, and heavy rain then delayed it until early in January.

Despite this bad start, fewer experimental field plots, a good spring and a trouble-free growing season, enabled the remainder of the experimental programme to be carried through without difficulty. The soil on both Barnfield, the classical mangold and sugar-beet area, and Agdell proved very difficult to work down and to get good seedbeds, and had to be rotary cultivated. Most of the cereal plots and all the beans were standing well at harvest; the root crops were harvested under unusually pleasant conditions, and dirt tares were low. Preparations for the 1960 crops did not clash with harvesting those of 1959.

On Broadbalk, the permanent wheat section carrying its eighth successive crop was sprayed with TCB/MCPA and the yields were generally higher than those from the unsprayed section, fallowed in 1956. Exceptions were those unsprayed plots receiving no inorganic nitrogen, where vetches and trefoil were abundant. The plots receiving inorganic nitrogen in two sub-sections after fallow gave low yields; they were water-logged during the winter and were very weedy. On the permanent barley plots of Hoosfield the campaign to eliminate coltsfoot (*Tussilago farfara*) was continued by spraying with the potassium salt of MCPA at 2 lb. a.e./acre in spring and with the ester formulation of 2 : 4-D at 1½ lb. a.e./acre in the autumn. Twitch (*Agropyron repens*) is gaining a hold on a few plots, and the affected areas were sprayed with "Dalapon" after harvest. On both fields wild oats were far fewer than for many years, and the policy of hand pulling, and late sowing of barley, seems to be producing excellent results. Lodging was much less than usual on both Broadbalk and Hoosfield.

The main development in field technique was to introduce a 40-inch flail-type forage harvester for crops of grass and clover at the silage and hay stage. A standard machine was slightly modified to reduce the air speed, and the grass, after cutting, is diverted by a shield from the delivery chute into an expanded-metal box carried at the rear. This is emptied on to a cloth ready for sampling and weighing. The machine gives a cleaner and closer cut than does the conventional type of mower, and eliminates raking, with its attendant losses. It saved much time and labour. An uneven or stoney surface may contaminate the sample, but no soil is drawn up when the machine works on level ground. The machine is not suitable for lucerne, which is so lacerated that rapid changes and losses are likely to occur in the sample.

The flail harvester was used for the second cut of the Park Grass plots. After the sample cuts had been taken the rest of the field was cut by the machine working as a normal forage harvester. The silage and hay plots on the two Ley–Arable experiments were used to compare the new technique with the old.

Moles were again active in the winter on some of the Park Grass plots, but were controlled with poison bait.

Cropping

Of the 467 acres farmed, 241 were under arable crops, 156 under short-term leys or lucerne–grass mixtures and 65 under permanent grass. The main arable crops were wheat (95 acres), barley (45 acres), beans (24 acres), oats (15 acres), potatoes (28 acres), and mangolds, sugar beet and kale (15 acres).

The cropping system is largely dictated by the requirements of experiments, but is based on a rotation of wheat, spring barley and either roots or beans. The acreage of potatoes is as large as can be handled conveniently, enough kale is grown for the needs of the stock and the sugar-beet area is kept small because our land is unsuitable. Beans are an alternative to the root crops, for they prevent the too-frequent cropping with cereals and the build-up of footrot diseases. Arable fields are rested periodically under grass or lucerne–grass leys, and are usually left down for 4 or more years, depending on the state of the sward.

This system is flexible and represents a compromise between the often conflicting demands of pathological experiments for clean, fertile sites and those of fertiliser experiments for sites likely to show a good response to nitrogen. Cropping is further complicated by restrictions on the use of phosphate and potash on some fields. Several such areas are now in " cold storage " under long-term grass leys.

Crops

Cereals

The summer suited all the cereal crops sown early, as were all spring crops at Rothamsted. They came into ear earlier, had a shorter straw and ripened about 3 weeks earlier than usual. There was some lodging with very high levels of nitrogen. There was less disease than usual. Spring wheat yielded up to 45 cwt./acre, barley

and oats up to 40 cwt./acre and winter wheat, though more variable, yielded up to 50 cwt./acre. Of two areas of Cappelle wheat sown in early February, one yielded 43 cwt./acre and the other (on a reclaimed orchard) 27 cwt./acre.

Cappelle was the main variety of winter wheat, and Koga II the main spring wheat. Proctor was the only barley variety. The oat area was divided between Blenda and Condor, with some Eagle for special experiments, but in 1960 only Condor will be grown on non-experimental areas.

Hormone herbicides were used on most of the cereals. CMPP and TCB/MCPA were used more than previously because of chickweed (*Stellaria media*), cleavers (*Galium aparine*) and other weeds resistant to MCPA and 2 : 4-D.

Beans

The acreage of winter beans was small, and spring ticks occupied the main area. Most were sown before the end of February, and the plants podded up well despite the drought. As this developed, the leaves wilted and dropped off by late July, and the crop ripened very quickly and early. Mechanical weed control presented no difficulties. A single application of " Metasystox " controlled the bean aphis (*Aphis fabae*) attack, which was severe enough to kill plants on unsprayed plots. Harvesting was by combine-harvester; the yield of the winter crop averaged 28 cwt./acre and the spring ticks 23 cwt./acre. In an experiment winter outyielded spring beans by over 10 cwt./acre.

Preliminary results with new weed-killers on beans are given on p. 177.

Potatoes

Conditions for planting were not ideal, as the ground below the surface was too wet. Growth was satisfactory in the early part of the season, but slowed as the drought developed. Weeds were easily controlled by mechanical cultivations, the necessity for which was well demonstrated by plots on which these were omitted, where yield was lowered by nearly 70%. The heavy rain in July led to secondary growth, which, combined with severe common scab, gave the tubers a bad appearance and made them difficult to sell.

The small area of Arran Pilots were difficult to lift because the ground was so hard; both yield and quality were poor.

There was enough late blight (*Phytophthora infestans*) to warrant a preventive spraying in August, but this probably had no beneficial effect because it was followed by dry weather. Yields were generally satisfactory, averaging 10–12 tons/acre of both Majestic and Ulster Supreme.

Preliminary results with new weed-killers for this crop are described on p. 177.

Kale and Sugar beet

Both crops were sown early and started well, but later wilted in the hot spells. There was no flea-beetle attack, and a threatened attack by the leaf miner (*Pegomyia betae*) to the sugar beet was pre-

vented by spraying with DDT; a spraying with "Metasystox" against virus yellows was too late to be fully effective. Both crops continued growing well into the autumn; the sugar beet yielded 11½ tons/acre of washed beet with an average sugar content of 18¾%; the kale yield was estimated to be 25 tons/acre.

Grassland

Good growth was made early in spring, and cattle were turned out from the yards in the latter half of April. The larger head of stock carried kept on top of the grass, and as the drought developed grazing became extremely scarce. There was a temporary improvement in July, when growth was rapid, but the grassland remained bare throughout the autumn, and supplementary food had to be given to stock by the middle of October.

Because of the unfortunate experience last year, the area for hay was lessened, and provision was made to dry hay bales, but this was not necessary. About twice as much silage was made this year as last and the quality was much improved; the 40-inch forage harvester greatly facilitated this work and enabled several areas, too small for haymaking operations, to be dealt with profitably.

Hay from the first cut of grass was made and stored in excellent conditions during June, but yields were light, and a second cut from the lucerne–cocksfoot mixtures was carted before the end of July. Some of the early-made hay tended to heat in the stack, perhaps because the outside parts of the plants dried rapidly and gave the impression that the hay was drier than it really was.

Livestock

Cattle

The policy of buying store cattle at about 18 months old and fattening them during the following summer and autumn remained unchanged. Those bought in 1957–58 did not do well on the very lush autumn grass of 1958, and many had to be brought into covered yards for finishing. Sixty-one Hereford and Hereford-cross bullocks were bought in the winter of 1958–59 for outwintering, but the grassland became so badly poached in the wet weather that they had to be moved into an open yard near the farmstead.

Grazing was very scarce throughout the summer and autumn of 1959, and had to be supplemented with grass toppings from fields and grass baulks which were cut by the forage harvester. Kale was fed in mid-October, and the most forward beasts were brought into yards in mid-November for finishing off. Altogether 103 cattle were sold fat during the year. A further 61 dehorned cattle bought in November were run outside while the kale lasted. They have now been brought into the open yard near the farmstead to facilitate the feeding of silage.

Sheep

The new flock of Half-bred gimmers bought in 1958 were crossed with Suffolk rams. Forty-two home-bred Suffolk × Scotch Half-bred tegs, selected from those used on grazing plots during the summer, were kept for breeding. As the whole flock was composed

of maiden ewes, the lambing percentage was lower than last year; the Half-breds gave 139% and the home-bred sheep 105%. Some trouble was experienced at lambing time, and the ewes seemed rather short of milk. The use of rubber rings for tailing and castration was less satisfactory this year. Most of the lambs are being over-wintered and will be used on grazing plots in 1960.

As grass was scarce, the ewes were flushed on a lucerne–cocksfoot mixture in the autumn and were fed some oats.

Equipment

The concrete-sided silo built in 1958 was doubled in length and provided with a concrete floor and a suitable drainage system. It now holds about 150 tons.

A new 10-foot self-propelled combine-harvester enabled the older of our two machines to go to Woburn, and greatly facilitated harvest.

The platform corn drier was converted for use as a hay-bale drier. The 10-foot-high sides were made of hardboard, and a false floor of weldmesh was laid above the sack gratings. The fan of the radial-flow drying bins alongside was connected to the bale drier because the platform-drier fan provided too little air. About 10 tons of hay can be dealt with at each loading.

The use of a flail-type forage harvester for cutting and collecting the grass from hay and grass plots was studied carefully. It seemed that the method might be satisfactory, and the manufacturer co-operated in preliminary trials, after which minor modifications were made to the machine. Further trials through the season proved the success of the 40-inch-wide machine, both as a normal forage harvester and for plot work.

Buildings

A new general-purpose pitched-roof shed was built to store implements, trailers and timber.

Estate Work

In addition to routine estate maintenance and mechanical hedge cutting, the 8½ acres of derelict orchard in Delafield were cleared and ploughed, so finishing the clearance of land acquired in 1955. Several thousand larch- and spruce-tree stumps were bulldozed from 15½ acres in Claycroft and Longcroft fields, where the timber was felled about 25 years ago, and which have been under grass since. It is hoped to clear the areas and plough in time for cropping in 1960. A small area between Appletree and Park Grass plots is being cleared in a similar manner.

Woburn

Woburn suffered more than Rothamsted from the hot, dry summer, partly because much of the soil is sandy, and partly because there was less rain. From May to September, it averaged about 1 inch per month, about half the normal, and the total for the

year was 21·31 inches. Potato and sugar-beet crops, and the grassland were affected most by the drought. Conditions for the hay and corn harvest were excellent.

Although the wet autumn of 1958 meant we started the year with land work much in arrears, weather in late winter and early spring was so favourable that arrears were made up and spring cultivations started earlier than usual.

Drought continuing into the autumn made ploughing slow and difficult, and seedbeds for winter corn were secured only after many cultivations. Conditions improved in November and, as work was well forward, the planned acreage of winter wheat was increased.

At the end of the year most of the land after potatoes and sugar beet had still to be ploughed, and several areas ploughed early needed reploughing.

Cropping

Of the 127 acres farmed, 26 were wheat, 26 barley, 11 beans, 21 potatoes and 7 sugar beet, much as in previous years. There were small areas under kale, lucerne, rye and market-garden crops.

Crops

Cereals

Most of the wheat was spring-sown Koga II, and the barley was Herta. Drilled early, germination was rapid, and crops grew well in the early summer. They came into ear early when the straw was quite short, and there was little lodging.

Harvest was early and conditions ideal. The local storms missed the farm and the moisture content of the grain was low enough for it to be stored without drying. The Koga wheat yield averaged 28 cwt./acre and the barley 25 cwt./acre.

Beans

Most of the area was spring-sown tick beans, which got started well, but by the end of June the leaves of crops on the light land were withering and dropping off. Irrigation doubled the height of plants. Drought had less obvious effects on the heavy land, but the crop was not vigorous. Bean aphis (*Aphis fabae*) attack was less severe than at Rothamsted, but a spraying with " Metasystox " was deemed advisable. One field heavily infested with weeds was sprayed with DNBP. This killed the weeds, but severely checked the beans, which never completely recovered. The yield averaged 16 cwt./acre.

Potatoes

This crop was planted by machine during April. Growth was rapid but this slowed later, especially on the lighter soils, as the drought developed. It restarted after rain in July, but by early August growth had almost stopped. The haulm then died quickly, from a combination of drought, late blight (*Phytophthora infestans*) and, in places, a severe aphis (*Aphis nasturtii*) attack. What remained of the tops was destroyed mechanically. Lifting conditions were ideal.

King Edward VII was the main variety grown. Yields averaged 8 tons/acre on the light land and 9½ tons/acre on the heavier land. However, on one area where there was an attack by the potato-root eelworm (*Heteroderea rostochiensis*), the yield was only 5 tons/acre. Not only were the tubers from the light land rather small and badly shaped, but about 16% were partially dehydrated and soft. The percentage ware (1⅝-inch riddle) from these areas was about 57%.

Sugar beet

The seed germinated rapidly and evenly, and the crop grew well at first. It wilted badly during the hot spells in late June and July, but recovered after the July rain. During August and September many of the lower leaves withered and died. However, the plants continued to grow until they were lifted, and the roots were large and of good shape. The average yield of 17½ tons/acre was far higher than was expected; the sugar content averaged about 16%.

The crop was sprayed with dieldrin against the leaf miner (*Pegomyia betae*), and twice with " Metasystox " against virus yellows.

Market-garden crops

The leeks were harvested over a period of several weeks in the spring, and substantial gains were made between each lifting. The average yield was 5½ tons/acre. Red beet, with a yield of almost 8 tons/acre, did as well as in the wet year of 1958, but the yield of early potatoes (5½ tons/acre) was considerably lower. The dry weather enabled weeds to be controlled far more easily than usual. The planting-out of the leeks in July coincided with a short period of rain, and they established themselves without difficulty.

Grassland

After rapid initial growth in the spring, recovery from early grazing, and subsequent growth, was slow. The grassland remained bare and burnt throughout the latter part of the summer and autumn.

The small area cut for hay gave a fair crop, which was made and carted in good condition.

Livestock

Cattle

Twenty Hereford-cross cattle were bought in December 1958 to consume sugar-beet tops, and make dung. It was hoped that these would fatten during the summer, but grass was so scarce that 10 were transferred to Rothamsted. To fatten off the rest by late autumn, the grass, from September onwards, was supplemented by hay. A further 15 cattle were bought in the autumn of 1959.

Pigs

The breeding herd of 20 Large White sows was maintained. The length of the progeny sold for bacon increased following the use of a longer boar, but the grading returns were disappointing, only 40% being in the AA+ or AA grades. The low prices for bacon pigs meant that more than usual were sold at pork weights.

Implements

This was the first year in which the Woburn farm had its own combine-harvester and baler, and all cereal and bean crops were harvested with them. When the drier is installed the farm will be equipped with all except the most specialised machinery.

The use of "Simazine" to control weeds in field beans and potatoes

Preliminary report

J. R. Moffatt & M. J. Hill

Field beans are rather a " dirty " crop, as they do not grow vigorously enough to smother weeds; though inter-row cultivations can control the weeds between the rows, expensive hand hoeing is needed to kill those in the rows. The many cultivations that make potatoes a good cleaning crop are similarly expensive, and there seems evidence that they may harm the crop. The triazine derivatives, " Simazine " and " Atrazine ", which showed promise as pre-emergence herbicides with these two crops, were tested in experiments at Rothamsted and Woburn.

Both substances are poorly soluble in water, " Simazine " only 5 p.p.m. and " Atrazine " 70 p.p.m., so they are not readily washed down into the soil. Crops whose roots draw water from below the surface soil are unlikely to be affected, and whether seedlings growing in the surface soil take up toxic doses depends largely on the amount of water there.

Experimental details

Tick beans were grown on heavy loam soil at Rothamsted and Woburn and were drilled 3–4 inches deep; Ulster Supreme potatoes were grown on heavy soil at Rothamsted, and King Edward VII on a sandy loam at Woburn. All crops were treated as usual up to planting, but shortly after weed-killer was sprayed on the soil by a tractor-mounted sprayer. The soil was left undisturbed by surface cultivations through the growing season.

All the experiments were in a single randomised-block design with threefold replication. The treatments consisted of three levels of " Simazine " ($\frac{1}{2}$ lb., 1 lb., and $1\frac{1}{2}$ lb. active material/acre), one level of " Atrazine " (1 lb. active material/acre), and plots on which weeds were not controlled. Difficulties in the layout prevented the inclusion of plots given customary cleaning operations, but the yield to be expected from such plots could be estimated from the surrounding potato crop at both Rothamsted and Woburn.

Full agricultural details of these experiments are given in Results of Field Experiments 1959.

Discussion

Weeds were counted and identified on 6 random sample areas of 180 sq. in. on each plot in June, except on the Woburn potato

experiment, where the chemicals did not affect the weeds. Tables 1 and 2 list only the most prevalent weeds in the bean crops.

TABLE 1

Tick Beans—Rothamsted—mean weed numbers per sq. yd.

	Fat hen (*C. album*)	Meadow grass (*P. annua*)	Slender Foxtail (*A. myosuroides*)	Chickweed (*S. media*)	Black bindweed (*P. convolvulus*)	Cleavers (*G. aparine*)	Total annual weeds	Wild * oats
O	24·30	132·60	3·60	4·50	5·70	2·70	177·60	0·164
S_1	1·20	—	—	—	2·40	1·60	7·20	0·078
S_2	—	—	—	—	0·40	0·40	0·79	0·010
S_3	—	—	—	—	—	0·40	0·40	0·012
A_2	—	—	—	—	—	1·20	1·20	0·007

* Counted on whole plots in July.

TABLE 2

Tick Beans—Woburn—mean weed numbers per sq. yd.

	Fat hen (*C. album*)	Meadow grass (*P. annua*)	Redshank (*P. persicaria*)	Chickweed (*S. media*)	Black bindweed (*P. convolvulus*)	Mayweed (*M. inodora*)	Total annual weeds	Wild * oats
O	93·20	8·80	304·00	93·60	71·59	16·39	558·06	6·51
S_1	0·79	1·20	68·80	5·20	57·60	—	138·79	0·71
S_2	—	1·60	33·19	4·00	12·40	—	46·93	0·97
S_3	—	0·79	6·79	—	5·59	—	13·20	0·06
A_2	—	0·40	6·79	—	7·60	—	16·00	0·98

* Counted on whole plots in July.

TABLE 3

Tick Beans—Mean yield cwt./acre

	O	S_1	S_2	S_3	A_2	Mean
Rothamsted:						
Mean (±1·18) ...	17·9	21·1	19·6	18·5	17·7	18·8
Increase (±1·44) ...		+3·2	+1·7	+0·6	−0·2	
Woburn:						
Mean (±0·93) ...	13·5	17·3	19·1	16·0	15·2	16·2
Increase (±1·31) ...		+3·8	+5·6	+2·5	+1·7	

Sprays

S = Simazine
A = Atrazine

Levels

1 = ½ lb. active material in 40 gallons/acre
2 = 1 lb. ,, ,, 80 ,,
3 = 1½ lb. ,, ,, 120 ,,

At Rothamsted " Simazine " at ½ lb./acre (S_1) almost excluded weeds, and little further benefit was obtained from the two higher doses. At Woburn, where the initial weed infestation was higher, the weed numbers were decreased more as the doses increased; even at the highest level 1½ lb./acre (S_3), the kill was less complete than at Rothamsted. " Simazine " and " Atrazine " had similar herbidical effects.

Table 3 shows that the yield of beans was increased by controlling the weeds, but there is a suggestion that the highest levels of " Simazine " decreased yield. At Rothamsted this year, the optimum dose seemed to be about ½ lb./acre, and at Woburn 1 lb./acre.

The difference between the efficacy of the materials on the two farms can almost certainly be ascribed to the differences in rainfall during the period immediately after they were applied. At Rotham-

sted 2·37 inches of rain fell in the four weeks after spraying, and at Woburn only 1·15 inches.

TABLE 4

Potatoes—Rothamsted—mean weed numbers per sq. yd.

	Fat hen (*C. album*)	Meadow grass (*P. annua*)	Redshank (*P. persicaria*)	Chickweed (*S. media*)	Black bindweed (*P. convolvulus*)	Cleavers (*G. aparine*)	Total annual weeds	Wild * oats
O	4·39	12·00	22·80	37·99	6·00	13·20	106·00	1·84
S_1	0·79	0·40	1·60	1·20	1·60	2·80	12·80	0·70
S_2	1·20	—	1·99	—	0·79	9·19	16·00	0·37
S_3	—	—	3·19	—	0·40	5·59	10·40	0·56
A_2	—	—	—	—	0·40	1·60	4·00	0·29

* Counted on whole plots in July.

TABLE 5

Potatoes—mean yield tons/acre

	O	S_1	S_2	S_3	Mean	A_2 *	Mechanical * weed control
Rothamsted: (±0·941)	4·55	11·91	11·81	11·16	9·86	12·40	13·66
Woburn: (±0·721) ...	3·16	3·96	4·57	3·60	3·82	3·64	9·59

* Yields from treated strips outside experimental area.

Sprays	*Levels*
S = Simazine	1 = ½ lb. active material in 40 gallons/acre
A = Atrazine	2 = 1 lb. " " 80 "
	3 = 1½ lb. " " 120 "

Table 4 shows that in the potatoes at Rothamsted all weeds except cleavers (*Galium aparine*) were controlled. "Simazine" at ½ lb./acre (S_1) dramatically decreased the population, and the two higher rates (S_2 and S_3) had no further effect. Table 5 shows the effect of weed competition on yields. As with the beans, "Simazine" at more than ½ lb./acre tended to lower the yield. The rainfall in the first 4 weeks after spraying was 1·79 inches and in the second 4 weeks 1·30 inches.

At Woburn neither weed-killer was effective, and the whole area became very weedy. The very low yields (Table 5) reflect the effect of intense competition with weeds in the dry light soil. The failure of the chemicals to control weeds at Woburn can be ascribed to the little rain, only 0·64 inch in the first 4 weeks and 0·51 inch in the second 4 weeks after spraying.

Yields of tubers from land adjoining the experimental areas on both farms suggest that "Atrazine", at 1 lb./acre behaved like "Simazine", and that controlling weeds by customary cultivations increased yield still further (Table 5). No errors can be given for these plots, however, and the figures can only be treated as a guide. The apparent superiority of mechanical cultivation over "Simazine" can be attributed to its greater success in controlling cleavers. By the end of the season this weed had formed an almost complete cover over the plots treated with "Simazine" or "Atrazine", for though the initial population of cleavers was small, the plants had no competition from other weeds and grew vigorously.

The combined effects of the drought and weed competition at Woburn led to a high proportion of partly shrivelled tubers. These amounted to 50% of the crop for the sprayed area but only 17% on plots where weeds were controlled by cultivations. A range of

crops will be grown on the sprayed land in 1960 to observe any residual effects.

In addition to the above experiments, some trial strips of winter beans were treated with "Simazine" and "Atrazine" in March 1959 when the crop was 4–5 inches high. Weeds already present were affected but were not killed by the spray, but the treated plots contained very few weeds that germinate in spring. Mayweed (*Matricaria inodora*), which was plentiful on the unsprayed strips, was well controlled. Beans on strips treated with "Atrazine" at 1 lb./acre, were stunted and damaged, but those treated with "Simazine" at $\frac{1}{2}$, 1 or $1\frac{1}{2}$ lb./acre were not visibly affected. Table 6 shows no loss of yield from the two smaller doses of "Simazine".

TABLE 6

Winter beans—Rothamsted—cwt./acre from unreplicated trial strips

O	S_1	S_2	S_3	A_2
27·8	27·4	27·9	24·3	21·3

The results in 1959 experiments, a year of exceptional weather, are considered promising and interesting enough to warrant further study.

The effect of two plant-growth hormones on the pod set and yield of field beans

J. R. Moffatt & M. J. Hill

Despite many husbandry experiments, progress in improving the yield of the field bean (*Vicia faba*) has been small. The yield depends on the number of pods which come to harvest, the number of seeds per pod and the weight of the seeds. Between varieties the weight of the individual seed and the number of seeds in each pod differ considerably, but within one variety these two factors are little affected by changes in field conditions. Only a small proportion of the flowers set pods that survive to harvest. The proportion that sets on individual plants depends on conditions in the crop, particularly on plant density, but the proportion per unit area of land does not, except at extremes.

In 1955 and 1956 field experiments of the randomised block type tested the effect of two plant-growth hormones, 4-chlorophenoxyacetic acid and α-(2 : 4 : 5-trichlorophenoxy) propionic acid, on the set of pods by spring-sown tick beans. The hormones were applied as a fine spray at a concentration of 5 p.p.m. starting soon after the first flowers opened. One lot of plants was sprayed twice, the two sprayings approximately a week apart, and another was sprayed weekly throughout the flowering period.

In 1957 only 4-chlorophenoxyacetic acid was used and the spraying was superimposed on an irrigation experiment at Woburn which incorporated a dung treatment. The plots were sprayed three times.

In all years yields were taken with a combine-harvester and pods were counted. In 1956 the seeds per pod were counted and the

weight per seed measured from samples taken before harvest. In 1957 flowers per plant and the pods set per plant were also counted.

TABLE 1

Mean yield of beans—cwt./acre

	No spray	4-chlorophenoxy-acetic acid		α-(2 : 4 : 5-trichloro-phenoxy) propionic acid	
		2 app.	*3 app.*	*2 app.*	*3 app.*
1955 Mean (±1·21)	12·0	13·9	12·0	9·7	11·0
		2 app.	*4 app.*	*2 app.*	*4 app.*
1956 Mean (±0·80)	24·4	25·7	27·0	23·0	22·7

Table I gives the yields and shows that the only significant effects were that two applications of α-(2 : 4 : 5-trichlorophenoxy) propionic acid decreased yield in 1955 and four applications of 4-chlorophenoxyacetic acid increased it in 1956. The number of pods per plant was not appreciably affected in either year.

TABLE 2

Mean yield of beans—cwt./acre

(±0·62)	No irrigation or dung	Irrigation	Dung	Irrigation and dung
No hormone	15·8	33·1	17·6	32·1
3 applications of 4-chloro-phenoxyacetic acid ...	15·5	32·4	17·4	34·8

In 1957 (Table 2) irrigation doubled the yield, and dung without irrigation increased yield slightly but significantly. The hormone increased yield only on plots with both dung and irrigation, and here the increase was small.

TABLE 3

1957—Pod, flower and bean counts

	Treatments								
	None	c	d	cd	h	ch	dh	cdh	
Pods/stem at harvest	5·60	9·20	6·00	8·00	4·80	7·50	5·80	9·20	±1·18
Beans/pods ...	3·08	3·04	2·71	3·09	2·94	3·20	2·84	3·13	±0·063
Wt. of beans gm.	0·400	0·404	0·408	0·394	0·408	0·429	0·444	0·415	±0·0201
Flowers/stem ...	36·80	66·90	40·30	61·00	36·20	59·20	35·40	60·20	±4·84
Flowers/pod set *	5·92	4·95	6·17	5·32	5·55	5·68	4·92	5·35	±0·297
Flowers/pod harvest	7·93	7·14	8·62	7·75	8·26	8·33	8·06	7·57	±0·491

* Counted 1 July.
c = Irrigation.
d = Dung at 12 tons/acre.
h = 4-chlorophenoxyacetic acid applied 3 times during flowering at conc. 5 p.p.m.

Table 3 shows that irrigation greatly increased the number of flowers per stem, but much of the increase was in flowers formed late at the top of the plant, few of which probably set pods. The increase in set at the lower nodes, therefore, was probably more than

is indicated by these figures. However, there are no node-by-node figures to support this idea.

The only effects of the hormone on either the pod set or the number of pods at harvest were to increase the set of flowers on the dung plots and to decrease it on the irrigated plots. By harvest these effects had disappeared. If, as is sometimes suggested, failure of pods to set and survive to harvest reflects a deficiency of hormone, the hormones we used did not correct the deficiency.

WOBURN EXPERIMENTAL STATION

C. A. THOROLD

A combine-harvester was used for all the cereal plots, including the classical experiments (continuous wheat and barley). Combining began on 4 August and ended on 21 August, facilitated by dry weather which preceded, and lasted throughout, except for showers totalling less than 1 inch in the period 10–13 August.

Grain yields were generally satisfactory, but potatoes and carrots were poor; some good yields were obtained from sugar beet, because sugar percentages were relatively large (about 19%), but yield of roots was less than in 1958.

Table 1 shows that the mean temperatures and hours of sunshine from May to October exceeded the long-period means. Rainfall for the year (21·3 inches) was below the long-period mean (24·8 inches), and much below 1958 (29·2 inches).

TABLE 1

Monthly mean temperatures (means of maximum and minimum), total rainfall and daily means of bright sunshine for April to October 1959, with departures from long-period means in brackets

Month	Mean Temperature (° F.)	Rainfall (inches)	Bright sunshine (daily mean) (hours)
April	49·1 (+2·7)	2·42 (+0·49)	4·90 (−0·01)
May	53·3 (+1·3)	0·66 (−1·54)	7·01 (+0·97)
June	58·7 (+1·2)	0·99 (−0·71)	7·40 (+0·79)
July	63·3 (+1·9)	2·68 (+0·24)	8·35 (+2·31)
August	63·4 (+2·7)	0·95 (−1·38)	7·32 (+1·46)
September ...	57·9 (+1·2)	0·09 (−1·94)	5·72 (+1·09)
October ...	53·4 (+3·9)	1·92 (−0·38)	4·69 (+1·30)

1955 was also a dry year (20·3 inches), after a wet one (28·0 inches); H. H. Mann then drew attention to the good corn crops and poor roots and potatoes and pointed out that a moist subsoil underlies the light sandy loams, so that relatively deep-rooted crops can maintain fairly good growth (*Rep. Rothamst. exp. Sta.* for 1955, p. 175). Table 3 compares crop yields at Woburn in 1958 and 1959, and Table 4 shows soil-moisture depletion.

FIELD EXPERIMENTS

Continuous wheat and barley

The Report for 1957 (p. 214) says that observations were to be made in the area called "permanent wheat and barley" on the cropping of wheat on the barley land and of barley on the wheat land. Strips of winter wheat (Squareheads Master) were drilled across the "continuous wheat and barley" areas in December 1958, and spring barley (Plumage Archer) on the remainder of these areas in March 1959. Both crops developed well, except the stand was incomplete

in plots which had received sulphate of ammonia in the first 50 years of the experiment. Unsatisfactory growth on these plots has been noticed for a number of years and was commented on by H. H. Mann in 1946 (*Rep. Rothamst. exp. Sta.* for 1939–1945, p. 254). No sulphate of ammonia was applied from 1927 to 1940; in 1941 and 1942 top-dressings were given at 2 cwt./acre. Nitrogen was given as " Nitro-Chalk " in the periods 1944–46 and 1949–54, and " Nitra-Shell " was given at $4\frac{1}{2}$ cwt./acre in March 1959. Since 1955, ground chalk has been applied to counteract acidity of the plots.

There is a double interest in the results from the cropping of the wheat and barley areas in 1959. The yields are to be considered in relation both to the preceding fallow and to the particular crop area. The beneficial effect of previous fallow was brief, and conclusions from this experiment must be deferred for a few years, because yields in the first year after fallow may be exceptional. However, it is of interest now to consider the " continuous wheat " and " continuous barley " area, the yields from the two unmanured plots (Numbered 1 and 7), and from the single plot which received dung (Numbered 11b) from 1877 to 1906 (giving 200 lb. ammonia/acre), and from 1907 to 1926 (giving 100 lb. ammonia/acre). The unmanured plots received nothing from 1877 to 1940, and the dung plots nothing from 1927 to 1940. Nitrogen has been given since 1940, as explained above. For a comparison with yields in the recent pre-fallow period, it seems desirable to use the mean of the four years 1951–54 with wheat, and the mean of the years 1951–53 and 1955 with barley, omitting 1954, when results were incomplete because of weeds. Although the wheat and barley areas were cropped in 1949 and 1950, the results were also unsatisfactory.

TABLE 2

Mean yields (4 years) of grain (cwt./acre) in Plots 1, 7 and 11b of " continuous wheat " and " continuous barley " areas, before fallow periods in 1955–58 (wheat) and 1956–58 (barley), compared with mean yields of grain (cwt./acre) for the same plots in 1959 when both wheat and barley were grown in both areas

	Continuous wheat area		Continuous barley area	
	Wheat	Barley	Wheat	Barley
Mean yield before fallow (1951–55)	9·3	—	—	11·8
Mean yield after fallow (1959)	20·5	23·1	26·1	21·6

The 1959 mean yield of wheat in the " continuous wheat " area, and of barley in the " continuous barley " area was about double the yield before fallowing. Table 2 also shows that wheat yielded more in the barley area (26·1) than in the wheat area (20·5), whereas barley yielded more in the wheat area (23·1) than in the barley area (21·8).

Green manuring experiment

Early potato yields averaged only 4·3 tons/acre, compared with 10 tons/acre in 1958 when May and June had more than average

rain. Despite the differences between 1958 and 1959, some treatments gave responses in both years; potatoes after trefoil undersown in the preceding crop of barley, and after ryegrass both yielded more than after fallow. The 1958 season favoured the growth of green manures in barley for testing in 1959.

The times of ploughing in green manures before barley affected yields more in 1958 than in 1959. Ploughing in during spring, gave average barley yields of 28·4 cwt./acre in 1959, compared with 23·2 cwt./acre with ploughing in during autumn; in 1958 the yields were 30·9 and 22·8 cwt./acre.

Six-course rotation experiment

In this experiment, using mineral fertilisers only, crops developed satisfactorily, except for clover, which became weedy and was ploughed in in June.

In April 1959 the barley on some plots became yellow, which was found to be associated with soil acidity (about pH 5). Hydrated lime at 1 ton/acre was immediately added. Since 1955 the original liming procedure has been changed, with lime given only once in 6 years. We shall now revert to the original scheme of giving 23 cwt./acre of ground chalk after potatoes for rye, and after sugar beet for barley.

Mean grain yields of barley were 28·6 cwt./acre, and of rye 27·1 cwt./acre, compared with 26·1 cwt./acre and 25·2 cwt./acre in 1958. Winter wheat (16·2 cwt./acre) in 1959 yielded less than in 1958 (20·6 cwt./acre). Main crop potatoes averaged 8 tons/acre, 1½ tons above 1958 when there was an early outbreak of blight. Sugar beet yielded over 12 tons/acre of roots and 46½ cwt./acre of sugar.

Ley and arable rotations experiment

Table 3 shows the mean yields for crops in this experiment in 1959 when there was a rainfall deficit (−3·46 inches) and sunshine excess (+0·65 hour/day), and in 1958 when there was a rainfall excess (+4·46 inches) and a sunshine deficit (−0·56 hour/day).

TABLE 3

Crop production (tons/acre) in the Ley and Arable Rotation Experiment in the years 1958 and 1959

Crop	1958	1959
Barley (grain)	1·4	1·7
Barley (straw)	1·5	1·3
Sugar beet (roots)	16·8	13·6
Sugar beet (sugar)	2·9	2·4
2nd year lucerne (85% DM)	1·6	2·4
Potatoes (total tubers)...	14·0	12·2
Carrots (roots)	7·3	6·1

Although sugar beet yielded less in 1959 than in 1958, the yield was satisfactory and greater than in the Six-Course Rotation Experiment. Lucerne is a deep-rooted crop which was presumably able to reach moisture at greater depths than the more shallow-rooted crops (potatoes and carrots), which yielded better in 1958.

The relatively large yield of lucerne in 1959 is remarkable in view

of the persistence of lucerne-stem eelworm (*Ditylenchus dipsaci*) in this area. The 3-year lucerne plots were fallow during 1959, in an attempt to prevent the eelworms developing further.

Market-garden experiment

Leeks were harvested between 4 March and 15 April, before the dry spell, and yielded 5½ tons/acre, similar to 1958. Early potatoes gave only 5½ tons/acre, compared with over 7 tons/acre in 1958. Globe beet gave 7·8 tons/acre in 1959, and 7·9 tons/acre in 1958.

Irrigation experiment

Soil moistures at three depths (0–3 inches; 3–9 inches; 9–18 inches) were measured on one irrigated grass plot and one nearby unirrigated grass plot at intervals from March to September. Table 4 shows the results at 9–18 inches, where moisture changes are particularly interesting.

TABLE 4

Soil moisture as percentage of the weight of samples taken at 9–18 inches, in irrigated and unirrigated plots carrying Cocksfoot grass

Sampling date	23 March	7 May	28 May	15 July	12 August	10 September
Irrigated	11·2	10·8	10·4	9·6	8·4	7·2
Not irrigated ...	11·2	10·8	8·0	6·4	5·2	3·6

The control plot received 8·1 inches of rain during the sampling period, and the irrigated plot had this plus the equivalent of 6·8 inches of rain as irrigation. On 10 September the moisture in the surface soil (0–3 inches) was 2·0% in the control and 4·8% in the irrigated plot, which had the equivalent of 0·5 inches on 1 September. Without irrigation the mean yield of dry grass was 31½ cwt./acre and 65 cwt./acre with.

Table 5 summarises the analyses for nitrogen made on samples of dry Cocksfoot grass from all (24) plots on each of the six cutting dates.

TABLE 5

Weights of dry grass (G) and of nitrogen (N) removed (cwt./acre) at each cutting, with and without irrigation, and at different rates of nitrogen application, in 1959

	Without irrigation				With irrigation			
	0·3 cwt.		0·6 cwt.		0·3 cwt.		0·6 cwt.	
Date of cut	G	N	G	N	G	N	G	N
6 May	7·1	0·2	11·0	0·4	7·8	0·2	11·4	0·4
27 May	6·8	0·2	7·7	0·3	11·5	0·4	14·3	0·6
22 June	1·6	0·1	2·0	0·1	10·0	0·3	12·8	0·5
14 July	2·0	0·1	2·2	0·1	9·2	0·3	11·3	0·4
11 August	8·1	0·4	9·6	0·4	12·0	0·4	16·5	0·6
9 September ...	2·3	0·1	2·6	0·1	6·6	0·2	6·5	0·3
Total	27·9	1·1	35·1	1·4	57·1	1·8	72·8	2·8

Nitrogen was applied 6 times, at 0·3 and at 0·6 cwt./acre.

Irrigation amounted to 1·8 inches in May, 2·5 inches in June, 1·5 inches in July, 0·5 inches in August and 0·5 inches in September (total 6·8 inches).

The mean yield with irrigation in 1959 (65 cwt./acre) was less than in 1958 when irrigation produced no response (81 cwt./acre with irrigation; 80 cwt./acre without irrigation). The low yield in 1959 can be attributed to the Cocksfoot sward deteriorating, for it contained much *Poa annua*. This weed constituted about 10% by weight of the " Cocksfoot grass " samples taken from two plots on 27 May. Because of this permanent grass was ploughed and resown with ryegrass in the autumn. Since the Cocksfoot S37 was sown in April 1954, it has given an annual mean yield of about 3 tons/acre (dry matter).

Jerusalem artichoke

Table 6 shows the weight of tubers lifted in February from the land where some of the tops were cut in October, 1958 (*Rep. Rothamst. exp. Sta.* for 1958, p. 189).

TABLE 6

Weight of Topine and of Jerusalem artichoke tubers (tons/acre) obtained when tops were cut green (October 1958), and when tops remained until lifting (February 1959)

	Tops cut	Tops not cut
Topine	6·6	8·0
Artichoke	14·4	15·3

Removing the top decreases the tuber yield of both Topine and Jerusalem artichoke but only little compared with the 20 and 11 tons/acre of green matter that was removed. The tops when cut in autumn may not make satisfactory fodder, because about 30% of the dry matter was " crude fibre ", so an experiment was started to see how earlier cutting of tops affects yield of tubers. The tops from part of an area planted in April 1959 were cut in July, and from another part in November. In July both artichoke and Topine gave about 8 tons/acre of tops: in this dry year the plants did not grow again, and a second cut could not be taken in the autumn as planned. The fresh weights cut in November were 5·4 tons/acre (Topine) and 6·8 tons/acre (Jerusalem artichoke), but many leaves had fallen before this. (Mann & Barnes.)

DUNHOLME FIELD STATION

R. Hull

G. H. Winder was appointed in June, and G. D. Heathcote in October to replace A. J. Gibbs. C. E. Cornford resigned in July.

In January R. Hull and A. J. Gibbs attended the meeting of the Virus Committee of the International Institute of Sugar Beet Research in Holland, and Gibbs attended the 22nd Congress in Brussels in February.

In October preliminary work began at Broom's Barn Farm, Barrow, West Suffolk, to which the work at present done at Dunholme will be transferred when buildings are ready.

Crops at Dunholme suffered from drought this summer. A few experiments at outside centres failed because of drought but, where soil water was adequate, exceptionally heavy yields were recorded, e.g., 30 tons/acre of roots ($5\frac{1}{4}$ tons/acre of sugar) at Pondersbridge, and 28 tons/acre of roots ($4\frac{1}{2}$ tons/acre of sugar) at Holbeach.

The British Sugar Corporation co-operated in and gave invaluable help with 118 field experiments in commercial sugar-beet root and seed crops and in mangold crops, as well as with regular surveys of diseases, aphids and other pests.

Incidence of sugar-beet yellows

The fine, dry spring and summer favoured aphids and the spread of yellows in sugar-beet crops. Few green aphids and virus-infected plants survived from the previous year, but infestations multiplied rapidly in May. An early migration of *Aphis fabae* from spindle led to large and general infestations of beet crops.

The scheme, developed during the previous 2 years, whereby farmers were warned of the need to spray proved valuable for checking the aphid attack. The agricultural staff of the British Sugar Corporation counted aphids in sugar-beet fields each day from early May until mid-July, and bulletins summarising the results were circulated each week. Growers were advised to spray their beet crops with systemic insecticide when average infestation for a district approached 0·25 green aphids/plant, or when *A. fabae* threatened to damage the foliage. The first warnings went out in mid-May, and by the end of May most growers in the eastern counties had been advised to spray. By the middle of June, growers in the early infested areas were advised to spray again. The average number of green aphids/plant in unsprayed crops in all areas reached 200 in early July and black aphids 2,000. In Yorkshire and Scotland most crops were sprayed in late June or early July. After declining in August and September, aphid infestations again increased on sugar beet in October and doubtless contributed to the large migration and egg deposition of *Myzus persicae* on *Prunus* spp. and *A. fabae* on Spindle.

The efficacy with which spraying controlled aphids varied greatly from field to field; spraying wilted crops at low gallonage in

hot weather was often ineffective. The results with different insecticides varied more than in previous years. Both green and black aphids quickly reinfested sprayed crops and some growers sprayed three or four times. Spraying ceased towards the end of July although infestations were still large in some areas and persisted into August. Of the total crop of 409,000 acres, 381,000 acres were sprayed once and about 190,000 acres more than once.

On average 15% of sugar-beet plants had yellows at the end of August. This was the same incidence as in 1958; it was less than half that of 1957 and 1949, two years of comparable aphid infestations when crops were not sprayed. The rate of spread of yellows was less than was expected from the aphid infestation, possibly because aphids were killed on early infected plants, which prevented the numbers of viruliferous alatae increasing quickly. In some crops the appearance of yellows symptoms was delayed by drought, which restricted leaf growth.

Twenty field experiments assessed the efficacy of spraying crops with systemic insecticides at the time recommended to growers. Yields were determined on fifteen, and on four the yield increase during October and November was assessed. Where *A. fabae* were numerous the beet showed an immediate response to spraying, and a greater yield increase resulted than was expected from controlling yellows alone. On a Sussex experiment spraying increased the yield of sugar from 38 to 74 cwt./acre. On all experiments harvested the average sugar yield response to an early spray was 26%, to a late spray 23% and to two sprays 28%. The increase came largely from increase in root yield, but sugar percentage also increased by up to 1·6; spraying appreciably improved juice purity. Yields increased during the autumn by 15% on unsprayed and by 16% on sprayed plots. (Hull.)

Sources of viruliferous aphids

To study the control of aphids in mangold clamps, a part of each of 21 mangold crops was sprayed with demeton-methyl about 2 weeks before harvesting and the sprayed mangolds were clamped separately from the unsprayed. Leaf samples of the unsprayed plants had few aphids on them in the autumn and, apart from one trial, leaves from the sprayed plants had none. Nearly all the aphids were *Myzus* spp., almost exclusively *M. persicae*; *Rhopalosiphoninus staphyleae* was not recorded. Aphids occurred on the crowns of unsprayed mangolds only when topping was incomplete. In the spring of 1959 half the clamps of unsprayed mangolds contained aphids. Only one of the clamps of sprayed mangolds had *M. persicae*, whereas five clamps of unsprayed mangolds were infested. *R. staphyleae* were more numerous in the clamps of unsprayed than of sprayed mangolds, except at one site where both clamps were heavily infested. Aphid infestation on the plants in trials repeated in the autumn of 1959 was much higher than in 1958.

During April, 17 of 23 mangold clamps examined in Lincolnshire had aphids, when *M. ascalonicus* was recorded 4, *M. persicae* 12 and *R. staphyleae* 9 times.

Aphids were found in 48 of 105 samples of weeds from beet-

growing areas examined between mid-March and early May. The weeds were of many species, but mainly *Senecio vulgaris*, *Stellaria media* and *Plantago* spp. *Myzus ascalonicus* was recorded 24 times, *M. persicae* 21, *Macrosiphium* spp. 10 and other species 21. None of the beet plants to which many of these aphids were transferred developed severe (necrotic) yellows. (Dunning.)

Yellows and mosaic viruses were more common in the wild beet on the East Anglian coast than elsewhere, whereas rust (*Uromyces betae*) was more common on beet on western coasts. Wild beet growing on foreshores of the Shotley peninsula of Suffolk were examined at regular intervals throughout the spring of 1959 and overwintering *M. persicae* were found at only one of eight sites. At this site aphids were found only on wild beet some distance above spring-tide level.

In the glasshouse, aphids preferred sugar beet watered or sprayed with tap water to those watered or sprayed with sea-water. The effect of watering with sea-water on aphid preference took 2–3 weeks to develop. Salt solution gave results similar to those obtained with sea-water. (Gibbs.)

Tolerant varieties

Some of the varieties selected at Dunholme for tolerance of yellows yielded more than commercial varieties where yellows, aphid infestation and drought were severe. At Sprowston the varieties were tested on sprayed and unsprayed plots, which had respectively about 10% and 100% of plants with yellows when harvested. On the unsprayed plots 8 of 11 outpollinated progenies exceeded the yield of the commercial varieties, but only 2 did so on the sprayed plots; the unsprayed progenies gave 106% and the sprayed 91% of the sugar yield of the commercial varieties with the corresponding spray treatment. At Erwarton (Ipswich), where aphids, yellows and drought were severe, 8 out-pollinated progenies gave on average 101% of the yield of the commercial varieties, but at Kirton (Spalding), where the crop had more soil water and was relatively free from yellows and downy mildew, they yielded only 95% as much as commercial varieties. Inbred lines 58/11/21, 58/45/694 and 58/103/233 always outyielded commercial varieties where yellows was severe, especially on the artificially infected plots at Dunholme, but gave less than the commercial varieties on the sprayed plots at Sprowston and at Kirton. Lines 58/19/303, 58/20/30, 58/93/1, 58/103/233 and 58/337/4S consistently outyielded the commercial varieties at all centres where tested. Hybrids between the older selected tolerant lines outyielded the commercial varieties by 30% on average at Erwarton and Dunholme, but on average they yielded only 97% as much as the commercial varieties at Spalding, and on the sprayed plots at Sprowston.

Out-pollinated seed produced from roots selected from plots of varieties Bush E and Sharpes E, infected either with severe (N) or mild (M) isolates of yellows virus, or with both isolates (NM), was sown at Dunholme and the plants artificially infected with severe yellows virus. The average yields (as percentage of commercial varieties) for the M, N and NM selections from Bush were respectively

90, 96 and 120%; for the selections from Sharpes they were 93, 103 and 101%.

The growth on the field of a hybrid (Q) between the tolerant varieties Q1S/1 and A7S/1 was compared with that of variety Sharpes E when healthy and when infected with yellows. By mid-June the dry-matter yield of Q was depressed 40% by yellows and that of Sharpes E 57%. By the final sampling in November, Q plants infected as seedlings yielded 58% more dry matter than infected Sharpes E, and the dry-matter yield of the healthy Q plants was 92% of that of healthy Sharpes E. Fresh weights of roots in November were identical for the two varieties when healthy, but the sugar content of Q was 0·6% higher than Sharpes E. When infected early, Q yielded 68% more sugar/root than infected Sharpes E. A late infection gave yields intermediate between the early infected and uninfected plants.

Leaf growth was restricted by drought throughout the summer as well as by yellows. The healthy Q plants had more leaf area than Sharpes E at first, but less in the autumn. At first the infected plants of both varieties had similar leaf areas but less than the healthy plants; in the autumn the infected Q plants had more than infected Sharpes E. A greater proportion of the total dry matter of healthy Sharpes E was in the crowns and petioles than of infected Sharpes E or of infected or healthy Q. Leaves of infected plants had a greater percentage dry matter than healthy leaves, but petioles and crown had less, as did the roots at first, but by November all roots had about 23½% dry matter.

The net assimilation rate of both varieties when healthy was similar at first, but Q had a rate half that of Sharpes E during the autumn. Q had a greater net assimilation rate than Sharpes E when infected; this difference persisted till harvest and largely accounts for the difference in yield of the varieties. In the field trials at Ipswich and Sprowston this variety gave 115, and 108% of the sugar yield of commercial varieties. (Hull.)

Insecticides

During the heavy aphid attacks of 1959 the insecticides listed in Table 1 were tested in the field for their control of aphids and yellows incidence. All insecticides, except endrin and ethion, significantly decreased the number of both *Aphis fabae* and *Myzus persicae*. At Dunholme " Rogor ", and especially fluoroacetamide and " P.P. 175 ", killed *A. fabae* slower than the other products. At Dunholme the number of syrphid larvae was decreased by all insecticides used except endrin.

All the insecticides except " Ethion " and endrin decreased yellows incidence and increased yield. Direct damage by aphids, especially *A. fabae*, was severe at all sites except Ely, and the yield increases from spraying resulted from control of both aphid damage and yellows.

The systemic insecticides " Disyston " and " Thimet " were tested in two root crops as seed treatments, broadcast or " in-the-row ", soil treatments, top dressings and various combinations of these in comparison with one, or two, sprays of demeton-methyl.

TABLE 1

Control of aphids and yellows by insecticides, 1959

Site	Chettisham, Ely	Nettleham, Lincoln		Dunholme Lodge, Lincoln		Dunholme Airfield, Lincoln	
Date of treatment ...	5 June	12 June		26 June		22 June	
Volume of spray used	40 g./a.	50 g./a.		55 g./a.		20 g./a.	
Treatment and amount applied per acre	% Yellows § 2 Sept.	% Yellows § 27 July	Sugar * yield	% Yellows § 6 Aug.	Sugar * yield	% Yellows § 5 Aug.	Sugar * yield
Demeton-methyl 50%, 12 fl. oz.	19	31	161	17	122	39	243
"Bayer 4536" 50%, 6 fl. oz.	15	31	166			43	240
"Rogor" 32%, 16 fl. oz.	17	31	159			49	229
Fluoroacetamide 15%, 20 fl. oz.	21	34	137			45 †	208 †
"N.P.H. 52" 50%, 12 oz.	18	31	146			46	206
"N.P.H. 60" 20%, 16 fl. oz.	17					45	204
"P.P. 175" 15%, 60 fl. oz.	19					45	233
"Phosdrin" 99%, 2 fl. oz.				23	108		
Endrin 20%, 30 fl. oz.				41	82		
"Ethion" 20%, 32 oz.		47	86				
Mean control	24	48	100	37	100	72	100
Least significant difference (P = 0·05) ...	5·6	7·4	25·4	14·6	Insig.	11·7	51·4
Control yield (lb. of sugar/acre)			3310		4513		1246

§ Angular transformation.
* Sugar yield as percentage of the control.
† Fluoroacetamide applied at 27 fl. oz./acre.

All seedbed treatments depressed seedling emergence, even "Thimet" seed dressing at the very low rate of 1 oz. active ingredient/acre and, in one trial, "Thimet" broadcast at 1½ lb. active ingredient/acre. Every "Thimet" or "Disyston" treatment decreased aphid infestations, especially of *A. fabae*, and also decreased the incidence of yellows at first; at the end of August, however, none affected the incidence more than did two demeton-methyl sprays. In one trial the best results were obtained by top-dressing the plants with granular "Thimet" or "Disyston" (1½ lb. and 3 lb. active ingredient/acre respectively) after singling. These treatments applied early (26 May), after a seed-dressing of the same material, controlled aphids for some time and decreased yellows incidence as much as did two demeton-methyl sprays applied on 10 June and 24 June. (Dunning and Winder.)

"Thimet" and "Disyston" were tested as seed and/or soil treatments with stecklings sown on 1 August 1958. Plant populations were lowered by the "Disyston" seed dressing (4 oz. active/10 lb. seed) and more seriously by the "Thimet" seed-dressing (2 oz. active/10 lb. seed), whereas the soil treatments (1½ lb. active/acre) had little effect. These tonic effects were probably increased by flooding of the plots 10 days after drilling. Seed treatment gave the best initial kill of aphids, but seed-dressing plus soil treatment controlled aphids for longer periods, and this was reflected in the incidence of yellows. Untreated plots had 5·6% of plants with yellows in

November and 15·1% in May; seed dressings, 3·8% and 10·3%; soil treatments, 3·0% and 8·2%; seed-dressings and soil treatments, 1·6% and 3·3% respectively. (Dunning and Dunham.)

Seed crops

Sugar-beet and mangold seed crops surveyed in June by the National Agricultural Advisory Service and British Sugar Corporation steckling inspectors contained few plants with yellows, as expected from the previous autumn's inspection of steckling beds. Most sugar-beet seed crops and two-thirds of the mangold seed crops had less than 5% infected plants. Downy mildew was more prevalent than usual; 3·4% of sugar-beet seed plants and 0·5% of mangold plants were infected. Sugar-beet seed crops raised under a mustard crop were particularly susceptible. The 1959 stecklings suffered severely from prolonged drought, and virus yellows was difficult to distinguish from yellowing from other causes. Only an occasional sugar-beet steckling bed was discarded because more than 1% of plants had yellows. All but 3% of mangold steckling beds had fewer than 1% of infected plants. (Dunham and Hull.)

So far, most stecklings with cover-crops for protection against yellows have been sown in spring, but in 1958 cover-crops for summer-sown stecklings were tested. Cover-crops sown between the beet rows were only half as effective as those sown in the row in keeping plants free of *A. fabae*. Buckwheat, linseed, mustard, Nida turnip, rape and maize had a satisfactory growth habit, and of these, linseed suppressed the steckling growth least. (Dunning and Dunham.)

Chemical defoliants sprayed on ripening sugar-beet seed plants killed the leaves quickly, but the main stem remained too wet for successful combine-harvesting and started to grow again after 3 weeks. Seed plants cut in the normal way dried in a few days. (Dunham.)

Seed treatment trials

Blackleg was unusually prevalent in 1959, the result of seed infection with *Pleospora betae* in the wet harvest of 1958. The organo mercury dust-dressings in commercial use failed to control blackleg, and a few severe attacks were traced to inadequately treated seed.

Sixteen insecticidal and fungicidal treatments were tested in unreplicated strips on sites in each of 18 factory areas, using rubbed and graded seed which had 56% of clusters infected with *P. betae*. As in previous years, the best fungicide was EMP steep, which increased seedling stand by 40%; " Panogen " and an experimental liquid fungicide gave 24% and 28% increases respectively. Dried seed sprayed with 6% v/w of a 0·2% solution of EMP gave slightly fewer seedlings than untreated. Dieldrin and γ-BHC dusted on to EMP-steeped seed gave more seedlings/oz. than EMP steep alone, but heptachlor gave fewer. All three insecticides gave slightly thinner final plants stands. The insecticidal effect of four commercial organo-mercury/insecticide dusts was influenced by the concentration and efficiency of the fungicides. The dressing containing γ-BHC

gave fewer seedlings/oz. of seed than those containing dieldrin or heptachlor, but a thicker final plant stand. Liquid insecticide treatments were tested for the first time. (Byford and Dunning.)

Steeping in EMP trebled, and " Ceresan " dust doubled the seedlings produced by seed with 60% of the clusters infected with *P. betae*. " Panogen ", a 2% organo-mercury dust, and this dust with griseofulvin, were better than " Ceresan " but less effective than EMP steep. Griseofulvin dust alone increased seedlings by 18%.

Sprayed seed gave poor results in the factory trials, probably because it was damaged by mercury when packed, possibly slightly damp, in polythene bags. Seedling emergence in the glasshouse from seed stored for 3 months in a polythene bag after being sprayed with 8% of 0·3% EMP solution, was only a tenth that of the seed stored in a hessian bag. However, diploid and polyploid seed treated at normal rates with " Panogen ", " Ceresan " and " Ceresan W " germinated normally after storage for 3 months in polythene and hessian bags.

Batches of Sharpes E seed from seed crops with 9–91% of clusters infected with *P. betae* were sown in the field either untreated or steeped in EMP. Steeping increased emergence by from 11 to 163%; the larger increases were with the most heavily infected samples. Untreated samples heavily infected with *P. betae* gave fewer seedlings in the field than expected from laboratory germination tests. The laboratory germination, which ranged from 43 to 92%, was not related either to *P. betae* infection or cluster size. The conflicting results reported last year were obtained with ungraded seed from the plots of a seed production experiment. (Byford.)

Other diseases

During June and July, 39 crops were reported with an apparently new disease, which has been named neck rot. The root rots and becomes hollow immediately below the crown, which often shrinks, furrows or splits. As the rot extends the plants wilt and die. The trouble is thought to be caused by weakly parasitic fungi (*P. betae*, *Fusarium* sp.) invading tissue injured earlier, possibly by frost, and was more prevalent in some beet varieties than in others.

In five seed crops grown without transplanting the number of plants with downy mildew varied little between November and March, but increased during April in three. In one the increase was delayed until May when, despite dry weather, 10% of plants had mildew.

Two Bordeaux-mixture sprays applied to a root crop between brairding and singling decreased downy mildew incidence in early June from 1 to 0·3%, and incidence did not increase later. Three " Dithane " sprays applied to a root crop in June and early July did not influence downy mildew, which increased from 0·5 to 1·8% affected plants during August. (Byford.)

Docking disorder was not seen during 1959. At Docking commercial Wyoming bentonite (40 tons/acre) increased yield of sugar beet roots by 10%, whereas local clay soil (120 tons/acre) only slightly increased yield. On microplots of Docking soil at Rothamsted, Wyoming bentonite increased yield by 33%, sterilised loam increased

yield by 53%, and 400 lb./acre of D.D. soil fumigant increased yield by 29%. (Gibbs.)

Several sugar-beet crops were reported as severely damaged by herbicidal sprays. Some were affected by drift while spraying nearby cereals, others from spraying sugar beet with machines used previously to kill weeds. Glasshouse plants showed abnormalities when sprayed with MCPB at a dilution of $1 : 2 \times 10^7$. Most sprays tested severely distorted sugar beet at dilutions between $1 : 2 \times 10^4$–10^5. MCPA, CMPP, MCPB produced the most leaf crinkle and 2 : 4 : 5-T the most contortion. Individual plants varied greatly in their susceptibility. (Wolfe.)

Sugar-Beet Manuring

The main work was again a series of field trials conducted in co-operation with the field staffs of the British Sugar Corporation, but results of the 1959 experiments are not yet known. This report gives the 1958 results.

NPK–dung trials

Fifteen 3^3 factorial experiments tested 0·6, 1·2 and 1·8 cwt. N/acre as sulphate of ammonia; 0, 0·5 and 1·0 cwt. P_2O_5/acre as superphosphate and 0·8, 1·6 and 2·4 cwt. K_2O/acre as muriate of potash. Ten of these tested the mineral fertilisers with and without dung.

Without dung, the most profitable average dressings were 1·2 cwt. N/acre, 1·0 cwt. P_2O_5/acre and 0·8 cwt. K_2O/acre. 1·8 cwt. N/acre gave less sugar than 1·2 cwt./acre. The response to phosphate was higher than normal because of two exceptionally responsive fields at Ipswich and Selby.

With dung, the most profitable dressing of nitrogen was 0·6 cwt. N/acre. Higher rates of nitrogen were usually deleterious. Even with dung, 0·5 cwt. P_2O_5/acre could be justified, but dung provided all the potash needed by the crop. The Ipswich experiment was exceptional because N up to 1·8 cwt./acre increased yield whether dung was applied or not.

Average responses were higher than in 1957, perhaps because the winter of 1957–58 was wetter than that of 1956–57. However, virus yellows was also less prevalent in 1958 than in 1957.

Ploughing-down and P and K trials

Ten experiments compared seedbed application of 1·0 cwt. P_2O_5/acre as superphosphate and 1·5 cwt. K_2O/acre as muriate of potash with the same fertilisers applied in the previous autumn and ploughed in.

Ploughing-down of P and K in the autumn was less effective than broadcasting in the seedbed, lowering yield by an average of 1·7 cwt./acre sugar. At Kelham and Colwick the yield lost from ploughing-down was 7·2 and 5·0 cwt./acre sugar respectively. At Allscott, Poppleton and Wissington ploughing-down was slightly beneficial, but it is not known why these fields differ from the rest. These results are similar to 1957.

Comparison of forms of nitrogen fertilisers

Eight experiments compared the effect of 0·6 cwt./acre N applied as sulphate of ammonia, calcium nitrate or urea in the seedbed or as top-dressing at the time of the last hoeing. An additional 0·6 cwt. N/acre applied either in the seedbed or as a top-dressing was also tested.

These experiments ended after 3 years. Calcium nitrate and urea were as effective as sulphate of ammonia in promoting sugar production, but calcium nitrate was more efficient than sulphate of ammonia and urea for producing tops. Splitting a dressing of 1·2 cwt. N/acre between the seedbed and the time of the last hoeing was no more effective than putting all in the seedbed, even in the wet spring of 1958. Delaying half the nitrogen did not lower the yield of sugar compared with putting all in the seedbed.

The average of all experiments showed that 0·6 cwt. N/acre in the seedbed was the most profitable fertiliser dressing. The increased yield of tops given by 1·2 cwt. N/acre may, however, justify the higher rate of nitrogen on farms where tops are fed to stock.

Growth analysis of sugar beet receiving different levels of nitrogen fertiliser

In 1959, plots of sugar beet given different quantities of N up to 1·8 cwt./acre in the seedbed, or partly in the seedbed and part as a top-dressing, were sampled seven times during the growing season to obtain information on the effect of N on growth. At the end of the season N did not significantly increase sugar yield, probably because drought was the limiting factor. In the early harvests, before water limited growth, significant responses in leaf area and dry-matter accumulation were obtained up to 1·2 cwt. N/acre. Even then there was no additional advantage in applying 1·8 cwt. N/acre and on 2 July this treatment caused a barely significant depression of leaf area and dry matter compared with 1·2 cwt. N/acre. (Adams.)

The effect of salt and potash on sugar beet on the Lincolnshire limestone soils

Six 2^2 factorial experiments on the Jurassic Limestone soils of Lincoln Edge tested the effect on sugar beet of 1·5 cwt. K_2O/acre as muriate of potash and its chemical equivalent of salt ($1\frac{3}{4}$ cwt./acre). All plots received 1·0 cwt. N/acre as sulphate of ammonia and 0·5 cwt. P_2O_5/acre as superphosphate. On average, salt and potash increased yield by 3·7 and 3·3 cwt. sugar/acre respectively. Both fertilisers together increased sugar by 5·8 cwt./acre. Response to salt was smaller in 1959 than in the wet summer of 1958. These results do not support the idea that salt acts because it can hold soil moisture in a dry spell. (Adams.)

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

B. Plummer was appointed to the staff and C. A. H. Hodge returned from Iraq. S. Harris was seconded from Messrs. Hunting to assist in the Soil Survey for a short time. A. O. Ballantyne, of the Colonial Pool of Soil Surveyors, completed his tour in Northern Rhodesia and is now in the British Solomon Islands; P. D. Jungerius is working in Ghana; the remaining members of the Pool are continuing the surveys in the countries to which they were seconded.

A. Muir was Chairman at a Seminar of a Baghdad Pact Working Party on Soil Classification; later he visited Russia to discuss the legend and draft soil map of E. Europe. He was also Chairman of the successful meeting of the F.A.O. Working Party on Soil Classification and Survey at Oxford, at which the first draft of the Soils Map of Western Europe was presented; a field trip was also arranged. D. A. Osmond compiled a second draft of the map at Ghent. Field excursions were arranged for the meeting of the British Soil Science Society at Sutton Bonington. A course of study of soils in the field was conducted at Juniper Hall Field Centre, Dorking, by B. W. Avery.

To hasten the work, detailed soil surveying was replaced by reconnaissance mapping; some detailed work to be published on the 3rd Edition maps of the Ordnance Survey is being completed, and areas surveyed on the new basis will be compiled on the 7th series maps.

Northumberland

Sheet 19 (*Hexham*)

Reconnaissance mapping was continued, and over two-thirds of the area is complete. Heather burning appears to inhibit peat growth on the flatter tops of Spitalshield, Eshells, and Burntridge Moors, thick peat being found only in the naturally poorly drained hollows. Elsewhere the coarse-textured Carboniferous till carries a thin black amorphous peat 4–12 inches thick which overlies a strongly gleyed, sometimes humus-stained A_1-horizon above a thin iron pan; in the B-horizon most of the stones weather to mineral grain aggregations. On slopes of 6°–12° medium-textured soils have gleyed A_2-horizons at an almost constant depth, apparently due to water flowing above the underlying solid strata. " Lateral gleying " is suggested as a name for this phenomenon.

Large well-dissected spreads of glacial sands and gravels are prominent along the South Tyne valley, forming freely drained, good arable soils, but around Whinnetly–Lipper Edge surface-water gleying is common. North of and adjacent to these sands brown earths develop where thin Carboniferous till overlies sandstone.

The Middle Limestone Group and the Calciferous Sandstone Series of the Lower Carboniferous formation produce striking escarpments of limited extent. Their presence, however, affects the

base status and drainage of the soils on the thin overlying Carboniferous till. (Ashley and Rudeforth.)

Yorkshire

Sheet 71 (Selby)

During the very dry weather work was resumed on the Mountain Limestone, north of Settle. Detailed survey was confined to the eastern side of Sheet 71, chiefly covered by Post-glacial sands, where 20 sq. miles were mapped. South of Holme-upon-Spalding-Moor, where the sands mainly overlie lacustrine clay, the water-table is close enough to the surface for both horticultural and farm crops to be grown. To the north, however, where they overlie Keuper Marl or glacial drifts and have a finer texture, wind-blowing is a problem; in the east the sands contain more flints and become a flint gravel in places.

The soil pattern is a sequence from iron-humus podzol to peaty gley soils and ferruginous deposits occur in the zone of fluctuation of the ground-water, their distribution suggesting lateral transport. Wind-blowing, marling and deep ploughing have obscured many morphological details.

In the same area a hill of Trias rocks, surrounded by the superficial deposits of the Vale of York, provides soils of the Worcester and Bridgnorth series. Gravels, derived from Carboniferous Sandstone, cap the hill and are slightly podzolised.

Attempts were made to use air-photo interpretation as an aid in mapping, but, as all the cultivated soils in the Vale appear similar on the photographs, the method was not helpful. On the Mountain Limestone they were useful in delimiting limestone pavements and soil boundaries marked by a definite vegetation change; they also helped in finding changes in parent material. (Crompton and Harris.)

Lancashire

Sheets 74 (Southport) and 83 (Formby)

During the early part of the field season forty-seven profile pits were examined and sampled for further data to include in the memoir.

Sheet 94, 7th series (Blackpool)

Reconnaissance mapping at 1 : 25,000 was started and 122 sq. miles surveyed; all the soils had been described previously, and suitable mapping units were chosen. Between Wesham and Garstang soils are developed on fresh water and estuarine alluvium and peat. The lack of prominent features necessitated more detailed work than was expected and slowed the rate of progress. Around Goosnargh on the Lancashire Plain the relief is undulating and gley soils on reddish coloured till, mainly of Triassic origin, are common. Small areas of steeper gradient and local patches of fluvio-glacial sand and gravel give rise to brown earths with more or less gleying.

Most of the horticultural land in W. Lancashire was mapped on Sheet 74, and the survey was completed by mapping 5 sq. miles in detail around Marton.

Among the *ad hoc* surveys was one of all the glass sand deposits in South-West Lancashire; this enabled the total glass sand reserves to be estimated and their suitability for different purposes to be assessed. First- and second-quality sands are associated with the Sollom and Crannymoor series. (Hall and Montgomery.)

Derbyshire

Sheet 125 (*Derby*)

Classifying and mapping soils was continued, and 39 sq. miles were completed, mainly in the east between the Erewash and Leen. Soils on Carboniferous, Permian and Trias strata were correlated with similar soils in Yorkshire. Much of the Coal Measures formation is disturbed by opencast mining, but the alternate sandstone and shale beds give freely or imperfectly drained sandy loams over weathering sandstone and grey clay loam overlying strongly mottled clay with impeded drainage respectively.

The scarp face of Permian strata gives rise to a complex of soils, but on the crest and dip slope the pattern is simpler and the soils of the Aberford and Micklefield series, first described from Yorkshire, are more suited to arable farming than are the gley soils of the Coal Measures. The Bridgnorth series occurred on steep, north-facing slopes of Bunter Sandstone, but on the Lower Mottled Sandstone both Bridgnorth and Newport soils occur, though difficult to map. Soils of the Mercaston or Hulland Ward series occurred on small drift-covered areas depending on its character. (Bridges.)

Shropshire

Sheet 166 (*Church Stretton*)

Field work is completed with the mapping of 30 sq. miles in Corve Dale and the Church Stretton valley; the soils on alluvial deposits in Corve Dale vary greatly. Time was spent studying whether the number of mapping units could be decreased, and a draft legend was produced. Mapping was done at both 1 : 25,000 and 1 : 10,560 scales, and a fair copy of the field maps at 1 : 25,000 was made. (Mackney and Burnham.)

Cambridgeshire

Sheets 173 (*Ely*) *and 174* (*Thetford*)

With the change from detailed to reconnaissance mapping, the area surveyed increased to 150 sq. miles. Most of this land is Fenland, where an upper and lower basin or low moor peat are separated by a continuous but not uniformly thick bed of " fen clay " of variable texture, deposited in creeks or reed beds. After the fens were drained, the upper peat largely disappeared, the fen clay is close to the surface and there is a widespread soil-sequence on low ridges and in depressions. Slightly raised, former river beds form meandering ridges (roddons) of silty, highly calcareous, prominently mottled soils.

In 1958 it was decided to survey Sheet 174, which covers most of the Brecklands and the 4,000-acre Thetford Forest. Apart from

the Fenland–Upland junction, the area is almost featureless. Reconnaissance excluding the Fenland showed that most of the Upland is underlain by Gipping Till—a chalk and sand mixture which on weathering produces the sandy material that is the parent material of most of the Breckland soils. Small areas of sands, gravels, Chalk and chalky clay occur in the north-east and south-east.

A few soils cover large areas, 50% or more of the sheet being covered by the Worlington series, which resembles the sol lessivé described by French pedologists. Other brown earths recognised are the Freckenham, Redlodge and Moulton soils.

About 10–15% of the Upland is occupied by brown, slightly calcareous sandy soils without a textural B-horizon over the till, and small areas of the Swaffham Prior series occur at the edge of the Fens. North and south of Thetford humus podzols develop on deep sand over either Gipping Till or gravels. Rendzinas (Wantage and Newmarket series) are of small extent adjacent to the Fens and on the steeper slopes of the plateau edge. (Seale, Hodge and Corbett.)

Bedfordshire and Hertfordshire

Sheet 147, 7th series (Bedford and Luton)

A reconnaissance survey of Sheet 147, which includes parts of the previously surveyed 3rd Edition Sheets 238 (Aylesbury), 239 (Hertford) and 220 (Leighton Buzzard), was started, and in the southern part about 100 sq. miles were surveyed. The mapping unit is the association defined as a group of topographically related soils and named after the most prominent member; nine associations were described.

Batcombe—naturally acid brown earths and gleyed brown earths on the drifts on the Chiltern Plateau. Soils: Batcombe, Berkhamsted and Winchester.

Icknield—rendzinas in the Chiltern Scarp zone. Soils: Icknield, Wantage and Coombe series, Steepland complex.

Halton—gleyed calcareous soils on chalky flinty Head over Chalk Marl in the Vale. Soils: Halton, Burwell and Wantage series, Ford End complex.

Coombe—brown calcareous soils on chalky flinty Head over Chalk on the platform in the Middle Chalk and upper part of the Lower Chalk. Soils: Coombe, Icknield and Charity.

Wicken—surface-water gley soils on reworked Gault and associated drifts in gently undulating, low-lying ground. Soils: Wicken series, Challow complex.

Hanslope—associated with Chalky-Jurassic Boulder Clay at various sites. Soils: Hanslope and unnamed soils.

Woburn—brown earths of low base status on resorted Lower Greensand and associated sandy drifts. Soils: Woburn and unnamed soils.

Flitwick—poorly drained soils on thin, sandy or gravelly drift over Jurassic clays on low-lying land. Soils: Flitwick, Denchworth and unnamed series.

Denchworth—surface-water gley soils on resorted Jurassic clays and associated drifts on low-lying sites. Soils: Denchworth and unnamed series. (King.)

Hertfordshire and Essex

Sheet 148, 7th series (*Saffron Walden*)

About 80 sq. miles were mapped in a reconnaissance survey.

The area is divided by the low Chalk escarpment between Royston and Newmarket, and most of the soils occurring north of it, developed on Lower Chalk, Gault and drifts associated with the Cam, are already described. They are Wicken, Burwell, Landbeach, Aldreth and Wantage series on lower ground and Newmarket, Icknield and Swaffham Prior series and Moulton complex on higher ground.

Over the scarp the pattern changes, and on the undulating dissected plateau of Chalky Boulder Clay the Hanslope and Streatham series are extensive. Glacial gravels mixed with till or brickearth-like material give flinty, well-drained brown earths of variable thickness of the Bengeo association. Glacial deposits overlying Eocene beds (mainly London Clay) yield Hanslope and Streatham soils, but soils on lower slopes, associated with gravels, are subject to lateral seepage over the London Clay surface. (Thomasson.)

Glamorgan

Sheet 154, 7th series (*Cardiff*)

Two hundred sq. miles were mapped on a reconnaissance basis in the Vale of Glamorgan using established series where possible after comparing the soils with possible correlatives elsewhere, thus keeping the number of new series to a minimum. East of Cardiff, Ludlow and Wenlock shales give soils of the Stanway and possibly Sannon series. On Devonian sandstones in an area with pronounced relief around the coalfield north of Cardiff the Eardiston series is dominant; on the marls the Bromyard and Middleton series and the Tanyard complex occur. Carboniferous shales yield poorly drained soils, resembling the Alton and Windley series, and the limestone produces Gower and Lulsgate series, the Lulsgate with and Gower without rock outcrops; plateau surfaces carry the Nordrach series. South-east of Cardiff on Trias rocks the Worcester series occurs on red marls, whereas the green marls give the Cogan series (freely drained) or Caerau series (poorly drained), all of which are fine-textured.

The narrow outcrop of Rhaetic strata yield the Ashton, Charlton Bank and Sand Hall series. Lias limestones are fairly extensive; the shallower soils are the Ston Easton series, and the deeper ones the Llanmaes series. Where drift influences the liassic clay, the poorly drained Dyffnan series is mapped on the northern part of the outcrops. The coalfield is bounded by glacial sandy and gravelly drift, which provides loamy soils of the Lisvane series (freely drained) or Pendoylan series (poorly drained). (Crampton.)

Berkshire

Sheet 268 (*Reading*)

Forty-two sq. miles were surveyed, forming an almost complete section of the geology of the northern half of the London Basin, in which all but six of the sixteen series mapped were previously named.

North of Twyford–Reading–Theale the south-dipping Upper Chalk emerging beneath the Eocene beds dominates the landscape. It has little influence on the soils, but its gradient makes the Eocene strata thin rapidly northwards, and their disintegration and erosion by the Thames have produced more relief here than to the south. Steep slopes, a variety of parent rocks of differing composition and extensive solifluction produce a complicated soil pattern.

South of the line, the London Clay forms an undulating plain broken by gravel-capped plateaux and, in the south-east, by the higher ground of the overlying Bagshot Beds. Considerable areas are covered either by level fluviatile gravels at different levels or by inclined surfaces of gravelly Head.

Of the soils mapped, 7 are brown earths, 2 podzolised soils, 2 calcareous soils and 5 are gley soils subdivided into calcareous or non-calcareous and dominated by either surface- or ground-water. (Jarvis.)

Gloucestershire and Wiltshire

Sheet 156, 7th series (*Bristol*)

Three areas on the Cotswolds were mapped in detail to establish mapping units on the Forest Marble and Great Oolite rocks and on the more complicated scarpland in the west; an area was also selected in the Avon valley between Chippenham and Melksham. The scarp is an important feature, particularly around Stroud and Bath, where there is much steeply sloping land. The lower slopes are dominated by freely drained, weakly acid, silty and fine sandy soils on steep slopes and by less-well-drained soils where the subsoils are fine-textured (Atrim, Martock and Long Load series). On the upper slopes imperfectly drained, coarse-structured soils (Trip series) occur with fine-textured, usually calcareous soils (Sherborne series) that are stony where flat and stoneless on slopes. The Sherborne series also occurs on the dip slope, where the Forest Marble, extending up to about 500 feet, comprises hard, flaggy limestones, calcareous grey clay and fine sands. The differences between the physical character of the Oolitic Limestone and Forest Marble are reflected in the more variable textures of the soils on the latter. The calcareous clays produce soils comparable to the Chickerell series.

In the Avon valley river terraces at 130, 140 and 170 feet and flinty loamy drift up to about 200 feet cover much of the Oxford Clay on which the Denchworth series occurs; the soils on the terraces and loamy drift require further investigation. (Findlay.)

Devonshire

Sheet 176, 7th series (*Exeter*)

A new centre was opened at the National Agricultural Advisory Service substation, Starcross, and about one-half of the 40 sq. miles covered by the Nuffield Farm Project was surveyed. The project is an attempt to study methods of bringing information to farmers, and the survey is needed to assess the extent to which results from the many field experiments can be applied. The area extends from

near Great Haldon on to Dartmoor and from Chudleigh and the Bovey Basin to Crediton, and the soils are derived mainly from granite or the Culm Measures.

On the granite, soils are freely drained except in the well-defined basins and valley floors where gley and peaty gley soils occur. The Middle Culm consists of dark grey shales with sandstone bands, but the Basement Culm includes hard mudstones, cherts, shales and sandstones with many diabase intrusions. Shallow brown earths occur on steep slopes of Culm shales, imperfectly drained soils on gentle slopes and on the small area of slopes less than 5° the soils are poorly drained. (Clayden.)

Sussex

Sheet 332 (*Bognor*)

The survey started in 1954 was resumed, and 30 sq. miles, mainly on the agriculturally important, but not easily distinguishable, Brickearth and Coombe Rock, were surveyed. In addition to the sequence of Hamble, Hook and Park Gate series, others were recognised in which the Brickearth is either incompletely decalcified or overlies Coombe gravel or raised beaches. The soil units are closely related to the landscape and amount of dissection, and can usually be mapped despite the very irregular junction between the Brickearth and the underlying deposits.

The raised beaches on the sides of valleys are incompletely delimited, and their lithology varies, but most of the soils are gley soils of the Calcetto series. The very variable alluvial deposits will be mapped as complexes. (Hodgson.)

Kent

Sheet 305 (*Folkestone*)

Primary survey of Romney Marsh was ended, and the final revision is almost finished. The memoir is being written and more profiles were described. Ground-water levels in representative soils were measured during this exceptionally dry season, and water samples were collected. Special studies of sub-surface porosity were continued using plaster of Paris and latex as infiltration media. The maximum expression of the pore-system occurred between 18 and 36 inches, but continued to at least 5 feet; some of the porosity is undoubtedly connected with the presence of the numerous *Lumbricus terrestris* observed. (Green and P. Askew.)

Other Work

In addition to preparing figures, etc., for memoirs, eleven soil maps are being drawn in the Cartographic Department. Many drawings and diagrams were made for several departments of Rothamsted Experimental Station.

Many areas were examined in detail and maps prepared from existing information. The sites investigated include horticultural and glass-house sites, experimental farms and fields and town-planning areas. Field trips were arranged for the meeting of the British Soil Science Society and for the F.A.O. Working Party.

INFECTIOUS DISEASES OF THE HONEYBEE

By

L. Bailey

Research at Rothamsted on infectious and other diseases of the honeybee began in 1934, and was supported by a yearly grant of £250 for the first 3 years from the British Beekeepers Association and an equal sum from the Agricultural Research Council, together with contributions from private individuals. The grants were primarily for work on diseases of honeybee larvae—brood diseases—incidence of which in England and Wales was causing concern. This review is of the research done at Rothamsted since then on infectious diseases of honeybees, and of relevant work elsewhere. There are infections of honeybees other than those mentioned below, but they are of less significance or incidence in England and Wales, and consequently have not been specially studied at Rothamsted. H. L. A. Tarr began the research: his work was mainly on the natural history of Bacillus larvae, established by White (1907) as the cause of American foul brood disease (AFB), and on the etiology of European foul brood disease (EFB).

American four brood disease

Sturtevant (1924), finding that reducing sugars, particularly in concentrations over 2 or 3%, inhibited germination of spores and vegetative growth *in vitro* of *Bacillus larvae*, suggested that this is why only sealed larvae, which have consumed all their food and the sugar it contains, become diseased. Tarr (1938a), however, found that spores germinated in a liquid medium of minced chicken embryo with concentrations of reducing sugars up to 12·5%. Furthermore, even small numbers of spores (100–140) sometimes would germinate in his medium. Lochhead (1933) also found that a few spores germinated below the surface of semi-solid media of entirely different constitution to Tarr's, and it seems possible, therefore, that spores germinate best in a critical, reduced-oxygen tension. Previously, Sturtevant (1932) found only large inocula of spores germinated *in vitro* and thought that this may explain why small doses fail to cause disease in bee colonies: a few larvae infected when 4–5 days old died in his experiments, but only when inoculated with massive doses of about 10 million spores each.

Tarr (1937a) showed that spores were necessary to infect larvae: vegetative cells, even in massive doses, did not infect. Unlike Sturtevant, however, he could not cause AFB by inoculating the food of 4–5-day-old larvae. He infected larvae more successfully by spraying them with spores than by feeding their colonies spores in syrup, and he noted young larvae seemed more susceptible. Subsequently Woodrow (1942) found one spore enough to cause disease provided the infected larva was younger than 1 day old: larvae

older than 2 days were immune. On this basis it is difficult to explain why only sealed larvae die of disease, particularly as spores germinate within 24 hours after entering the larval mid-gut (Woodrow & Holst, 1942). Furthermore, the vegetative rods do not grow much in unsealed larvae (Maassen, 1908), and may even diminish in numbers shortly after larvae are sealed (Holst, 1946). *Bacillus larvae* may not grow much in the larval intestine, as this is probably too anaerobic, or bacterial growth quickly makes it so (see EFB section below), particularly perhaps in the most rapid growth phase of the larva which starts on the 3rd day after hatching (Nelson, 1924). Larvae may ultimately be killed during a critical phase of pupation by the toxic enzymes that Patel & Gochnauer (1959) found in remains of larvae dead of AFB, and which may be liberated by *B. larvae* as it grows. The relatively few bacteria in the larvae then could invade the dead tissues, proliferate and sporulate.

Shortly after Haseman & Childers (1944) found that sulphonamide drugs effectively suppressed signs of AFB, experiments were made at Rothamsted to test the value of such treatment. Milne (1947) summarised his investigations and confirmed the effectiveness of sulphonamides in allaying disease, but emphasised that treatment was impermanent, because dormant spores of *Bacillus larvae*, now known to stay viable for at least 33 years (Haseman, 1959), can develop once the drug is exhausted. In view of the lessening of the disease in England and Wales since the implementation of the Foul Brood Disease of Bees Order of 1942, which enforces destruction of known diseased colonies, use of sulphonamides was not considered advisable, and work on chemotherapy of brood diseases was suspended at Rothamsted. Work continued abroad, however, principally in Canada and the United States: oxytetracycline (Terramycin) was found by Katznelson & Jamieson (1952b) to be an effective antibiotic, but it has the same limitations as sulphonamides. There is still controversy, even in countries where use of drugs is permissible, about the desirability of their use in preference to destroying diseased colonies.

European foul brood disease

Tarr began investigations at Rothamsted on EFB when there was considerable confusion, not only about the etiology of the disease, but even about its existence. He worked first on *Bacillus alvei*, a bacterium commonly present in remains of larvae that have died of the disease and was, at the time, usually considered the cause. Burnside & Foster (1935) described *Bacillus para-alvei* as an organism similar to *B. alvei* and causing a disease similar to EFB. Tarr (1936a) found that *B. alvei* and *B. para-alvei* were biochemically indistinguishable; their differences, which were slight, were solely morphological. Davis & Tarr (1936) also found *Streptococcus apis* (another organism often present in diseased larvae) was indistinguishable from *Streptococcus liquefaciens* or *Streptococcus glycerinaceus* (all now classified as *Streptococcus faecalis*: see Bergey's *Manual of Determinative Bacteriology*, 6th ed.). This was apparently independent of Hucker (1932), who had already identified *A. apis* as *S. liquefaciens* by cultural and serological tests. At first Tarr (1936b) thought *A. apis* or *B. alvei* were able to cause EFB: he

found that disease sometimes developed after larvae had their food inoculated with pure cultures of either organism and were incubated without nurse bees for 4 days at 35° before being returned to their parent colony. It seems likely that EFB was endemic in the experimental colonies he used, and this may have made results unreliable, but it is also possible that signs similar to those of EFB were induced in the inoculated larvae whose resistance was lowered by starvation (see below). Later, Tarr (1937b) realised, as had White (1912), that another organism always seemed to occur in diseased larvae, particularly in the early stages of their infection. It was hardly distinguishable morphologically from *S. apis*, but its presence was suspected when attempts to make cultures *in vitro* from larvae, apparently containing very large numbers of *S. apis*, failed. Tarr (1938b) attempted to cultivate the organism, which he now recognised as *Bacillus pluton* White, on a variety of media without success. However, he confirmed many observations of White (1912, 1920).

Thus Tarr usefully clarified the complicated bacteriology of EFB, and his eventual confirmation of White's original observations, which previously had not been accepted or had been considerably modified, encouraged continuation of work with the principal fundamental aim of cultivation, *in vitro*, of *Bacillus pluton*. Meanwhile Burri (1943) introduced further complications by claiming to identify *B. pluton* as a dissociant form of *Bacterium eurydice* White, another organism commonly plentiful in larvae with EFB. Miss E. Kops at Rothamsted could not verify Burris' observations (*Rep. Rothamst. exp. Sta.* for 1947) but found *B. eurydice* to be pleomorphic and in some conditions to resemble *B. pluton* morphologically. Miss Kops and Miss H. Finegan tested a wide variety of media and conditions for cultivation of *B. pluton*, but all were unsatisfactory. Later, attempts were renewed with the co-operation of Professor L. P. Garrod (St. Bartholomew's Hospital), and field trials with one of his isolates indicated the possibility that *B. pluton* could be cultivated as an anaerobe (*Rep. Rothamst. exp. Sta.* for 1954). A medium was eventually developed at Rothamsted which gave satisfactory growth of *B. pluton* in anaerobic conditions (Bailey, 1957a), and the first experiments made with pure cultures showed it to be the primary pathogen in EFB (Bailey, 1957b, 1957c). As the organism does not form spores, it was decided that *Streptococcus pluton* (White), suggested by Gubler (1954), was a more appropriate name. Apart from low oxygen tension, the major critical requirements of *S. pluton* for growth *in vitro* are a high ratio of potassium to sodium, unidentified constituents of certain yeast extracts, high inorganic phosphate concentration, and CO_2.

Unlike *Bacillus larvae* (the cause of AFB), *Streptococcus pluton* develops abundantly in the larval mid-gut, suggesting that the mid-gut is virtually anaerobic, which may explain the feeble development of *B. larvae* in growing larvae. *S. pluton* apparently weakens larvae directly by depriving them of food (Bailey, 1959a), which enables secondary invaders to develop abundantly and help kill the larvae. Typically, *Bacterium eurydice* is the first of these to develop, as it is commonly present in bee colonies, living normally, apparently harmlessly, in the anterior parts of the alimentary tract of adult

bees (*Reps. Rothamst. exp. Sta.* for 1957, 1958). Other secondary invaders, such as *Streptococcus faecalis*, which seems common in cases of EFB in continental Europe, but not now in Britain, are probably picked up from outside sources by foraging bees. *Bacillus alvei* is not always present, but tends to become established in endemically infected colonies: it seems to be the last of the secondary invaders, developing in larvae that have died (Bailey, 1959b).

Tests with sulphonamides against EFB were made at Rothamsted in 1946 and appeared ineffective. Various antibiotics, however, particularly streptomycin and oxytetracycline, were found by Katznelson *et al.* (1952) to be effective, and their use has become common in North America and Europe. Growth of *Streptococcus pluton* is completely inhibited *in vitro* by penicillin G (concentration 10^{-7}–10^{-9}); oxytetracyclin (10^{-5}–10^{-7}) and streptomycin (10^{-4}–10^{-6}) (*Rep. Rothamst. exp. Sta.* for 1958). Despite the great efficiency of penicillin G *in vitro*, it is ineffective *in vivo*, against both AFB and EFB, and probably because it is unstable, particularly at pH values about 4·0, such as occur in honey and larval food. Dormant cells of *S. pluton* are now known to remain viable for over a year, however, and they probably become well distributed within bee colonies from some infected larvae, which, nevertheless, survive. Such larvae void very many bacteria in their faeces before pupation (Bailey, 1959a). Thus, treatment with antibiotics has, fundamentally, the same disadvantages with EFB as with AFB—continued application of drugs is needed until dormant bacteria have been eliminated by consumption of contaminated food and cleaning of combs by adult bees, but there can be no certainty of when this has been achieved.

Acarine disease

After the mite, *Acarapis woodi* (Rennie), was discovered by Rennie *et al.* (1921), it quickly acquired the reputation of being very destructive to adult bees, because it was considered to cause the " Isle of Wight disease ", from which many colonies of honeybees were alleged to have died in the British Isles from 1906 until shortly after the time *A. woodi* was discovered. Accordingly, the limited research at first possible at Rothamsted on adult bee infections was aimed at improved remedial measures, particularly as surveys between 1941 and 1944 (Butler, 1945) showed 20% of colonies infected and widely distributed in England and Wales. It had already been shown elsewhere that careful application of the vapour from Frow's mixture (nitrobenzene, safrol and petrol), or from burning sulphur, killed mites with no apparent damage to the bees. Butler (1941) also found terpineol vapour effective in laboratory tests. Later, more extensive field and laboratory trials were made with a variety of fumigants, including newer acaricides applied as smokes and reported effective by continental workers (Bailey & Carlisle, 1956). Briefly, Frow's mixture was found effective when applied in cold autumn weather, but infested bees eventually died in winter earlier than is normal. Thus, although the chances of heavy infestations recurring next season can be decreased, even if not eliminated, treated colonies are more likely than uninfested ones to die in the late winter because their numbers are abnormally low. Newer

acaricides of the di-(*p*-chlorophenyl) methyl carbinol ("Dimite") type are convenient for spring or summer use and are more effective than sulphur fumes. Repeated applications are necessary, however, unless they are used in warm weather, but then the colonies may be damaged because the smoke over-excites the bees.

Acarapis woodi achieved its bad reputation without any quantitative observations or experimental evidence about the pathology and epidemiology of infestation. Accordingly, since 1951, records were kept at Rothamsted of infestation and mortality of colonies that were not treated, and these showed that infestations in endemically infested hives are usually suppressed naturally. The proportion of total colonies examined that was detectably infested was similar to that found in the national surveys made in 1941–44, but most were only lightly infested, and when colonies found infested at any one time were graded according to the degree of infestation the numbers in each group fell exponentially as the degree of infestation increased. Few colonies ever had more than 30% of their bees infested during any one season. Obvious damage to colonies was found only with these heavy infestations, and then only in late winter: the very few with more than 75% bees infested usually die about March (Bailey, 1958). The effect of infestation on the life of individuals is slight and difficult to detect in summer bees. Queenlessness and inactivity of colonies in poor seasons are principal factors causing increased infestations (Bailey & Lee, 1959).

Thus, heavy infestation is the consequence of events unfavourable to colony development: it may be more common after several poor seasons, when the bees are kept alive by artificial feeding. On this basis, the apparent close association of mite infestation with "Isle of Wight disease" (Rennie *et al.*, 1921) may be reinterpreted. This disease probably had no single cause; rather, the name included a wide variety of debilities with similar signs (Rennie, 1923). Heavy mite infestation may well have resulted from, not caused, these various ailments, which on some occasions at least, including those of Rennie's investigations, occurred in very poor seasons. From its known wide distribution, *Acarapis woodi* was probably endemic in honeybees before the days of the "Isle of Wight disease": it has been found in *Apis mellifera* in most parts of Europe, including Sardinia and Mallorca, in Russia and in South America. It also occurs in *Apis indica* in India (Sardar Singh, 1956) and in *Apis mellifera adansoni* in the Belgian Congo (Benoit, 1959). Its apparent absence from Scandinavia, North America, Australia and New Zealand (Jeffree, 1959) seems remarkable, therefore, and deserves study.

As heavy infestation by *Acarapis woodi* is usually symptomatic of a poor economy, treatment, however successful in killing mites, may not be expected to produce a striking response in colony development. The value, therefore, of treatments that are directed solely against mites needs careful consideration, particularly as present methods have some detrimental effect on bees.

Nosema disease

In a survey in 1941–44 (Butler, 1945) adult bees infected with *Nosema apis* Zander were detected in about 5% of colonies widely

distributed in England and Wales in April and May, the period when an acute peak of infection occurs in endemically infected colonies. This annual epidemic had been reported from Switzerland (Morgenthaler, 1939) and was confirmed at Rothamsted (*Rep. Rothamst. exp. Sta.* for 1939/45). Widespread infection of colonies at Rothamsted was first noticed in 1946, and from 1947 to 1950 Hassanein studied the natural history and pathology of the infection. Earlier workers showed that heavy artificial infection in autumn killed colonies in winter (White, 1919; Morgenthaler, 1941); that infected queens soon become unable to produce eggs (Fyg, 1945) and that hypopharyngeal glands of infected bees become prematurely atrophied (Lotmar, 1936). Hassanein (1951, 1952a) confirmed the last two observations, and found that brood-rearing was lessened in naturally infected colonies in spring, presumably because infected bees produced less hypopharyngeal brood-food, and that infected bees began foraging earlier and had shorter lives than uninfected individuals (Hassanein, 1953). There was plenty of experimental evidence, therefore, that infection with *N. apis* was pathological—more so, to individual bees, apparently, than infestation with *Acarapis woodi*.

Endemically infected but otherwise normal colonies are rarely obviously affected, however; this follows from the extent to which infection is naturally suppressed in such colonies during the summer. Burnside and Revell (1948) considered that increased temperature of the cluster, as brood-rearing increased, could account for the suppression of infection, and they confirmed results of Lotmar (1943a) showing that temperatures over 35° suppressed development of the parasite in individual, caged bees. An alternative explanation was that transmission of parasites to newly emerging bees, which are free of infection, ceases in summer when bees fly freely and defaecate outside the hive, and this was tested by experiments at Rothamsted in which bees were transferred to uncontaminated combs in early summer (Bailey, 1955a, 1955b). This treatment usually lowered infection to undetectable levels with no recurrence the next year. It seemed reasonable to suppose, therefore, that infection normally persisted in summer as faecal contamination deposited on combs the previous winter, and the decline of infection in summer reflected fewer spores left on combs to infect new bees. Recent experiments (Bailey, 1959c) showed that artificially infected bees, introduced to endemically infected colonies in summer when infection was naturally diminishing, all developed similar numbers of spores to those in naturally infected bees in spring when natural infection was high. Thus, high temperature seems to be unimportant, and the amount of infection on combs seems fundamental to the natural history of infection.

Means of decontaminating combs were developed: the best found was fumigation, at normal temperatures, with fumes of formaldehyde for empty combs, or with vapour of acetic acid for combs with food in them. The effectiveness of acetic acid was confirmed by beekeeping institutes abroad (Gavrilov, 1957; Jordan, 1957; Lunder, 1957). At Rothamsted almost all the bees were transferred to such combs in early summer 1954, and the percentage of colonies with detectable infection fell from between 50 and 90 to 7 the following spring (*Rep. Rothamst. exp. Sta.* for 1955). Many

colonies were also treated with fumagillin (see below), which may have helped, but there was no significant difference between colonies that received both treatments and those only fumigated (Bailey 1955b). These experiments were made in a poor season when infection locally, and generally in England and Wales, rose from 10 or 20 to 35 or 40% of colonies (Min. of Agric., Fish. & Food, 1956). Absolute elimination of infection seems unlikely by the methods employed, but keeping levels of infection low would be acceptable provided this could be done cheaply. Fumigating spare combs only, before re-use, has so far proved inadequate, but at Rothamsted colonies are handled more often than in normal beekeeping, and the seasons since the trial have been very poor. Nevertheless, this simplified method has some value, because the numbers of potential parasites are decreased; the susceptibility of wax-moths, particularly their eggs, and *Streptococcus pluton* to the same treatment (*Reps. Rothamst. exp. Sta.* for 1955, 1958) gives it added value.

Direct evidence of the effect of manipulation on infection of colonies was obtained (*Rep. Rothamst. exp. Sta.* for 1958) when infection increased significantly in colonies inspected monthly in winter. A similar but smaller effect may be expected in summer, and the high levels of infection of package bees from the southern states of the United States (Reinhart, 1942; Farrar, 1947) may derive from the handling they undergo followed by their long journeys. Infected samples of bees received for diagnosis about April and May by the National Agricultural Advisory Service have risen from the 1941–44 level of about 5% to approximately 20% since about 1953. This may not be entirely attributable to poor weather: there is no doubt that transportation of bees, mainly to orchards in spring and to heather in autumn, is more frequent now than during and shortly after the war of 1939–46, and transportation seems an important cause of high levels of infection (Bailey 1955a). Commercial beekeepers have considerably higher infection in their colonies than have beekeepers in general (unpublished data, Min. of Agric., Fish. & Food) and probably transport their bees more.

After the discovery of the striking effect of fumagillin in suppressing infection by *Nosema apis* (Katznelson & Jamieson, 1952a) field trials were made with it at Rothamsted. Feeding fumagillin in autumn prevented or retarded development of infection the following winter (Bailey, 1953a, 1955b). Results were not wholly satisfactory: infection was apparently always checked or diminished by treatment, but absolute elimination seemed unlikely. Repeated autumn application may eventually succeed: spring treatment alleviates the immediate acute infection, but comb contamination is less likely to be decreased.

It is necessary to consider the value of possible treatments and the circumstances in which they are applied. The degree of infection in spring with *Nosema apis* reflects to some extent the degree to which other circumstances of honeybees were unfavourable the year before. Lotmar (1943b) found a significant positive correlation between wet summers and the degree of infection the next year, and the only striking fall of infection in England and Wales in recent years was after the unusually good season of 1955 (Min. of Agric., Fish. & Food, 1956, 1957, 1958). In poor seasons the natural

cleaning of combs is probably decreased, because brood rearing and nectar gathering is diminished and defaecation by infected bees in the hive may be more frequent than in good seasons. Colonies should not be disturbed in poor seasons, and drug treatment seems most useful at the end of such seasons. Comb changing would be most likely to eliminate infection in good seasons.

More fundamental studies of infection in individual bees show that the parasite is first established at the anterior and posterior ends of the ventriculus, usually mostly at the anterior end, with a region of minimal infection centrally (Bailey, 1955c). The last region has many cytoplasmic granules of calcium phosphate which disappear when infection penetrates the cells. Their presence may, therefore, initially inhibit growth and development of *Nosema apis*. Infection soon disappears from bees fed syrup containing fumagillin, leaving apparently normal cells except at the anterior end of the ventriculus, where infection persists even after continuous drug treatment for several weeks (Bailey, 1953b).

Amoeba disease

Malpighamoeba mellificae Prell was studied at Rothamsted first by Hassanein (1952b), who confirmed that an annual epidemic, similar in character to that of *Nosema apis*, occurs in adult bees of endemically infected colonies. This annual epidemic appears to have the same explanation as that of *Nosema apis*; transference of infected colonies to non-contaminated combs in early summer eliminated infection, and transference of combs from infected to uninfected colonies in autumn introduced infection which became epidemic the following spring (Bailey, 1957d). Cysts of *M. mellificae* on combs were killed as readily as spores of *N. apis* by vapour of acetic acid, but fumagillin did not affect the development of *M. mellificae* in infected bees (Bailey, 1955d).

The incidence of infection with *Malpighamoeba mellificae* in England and Wales was less than 1% in 1941–44 (Butler, 1945), but in recent years it has risen to about 3%. The rise is coincident with that of *Nosema apis* mentioned above, and seems likely to be for similar reasons. Infection is restricted to the south-east of England, however, particularly near London (Min. of Agric., Fish. & Food, 1956, 1957, 1958), which is strikingly similar to infection reported from Denmark, where most is near Copenhagen (Fredskild, 1955). The reason for this is not clear, but bees may be examined and disturbed more frequently in urban than rural regions. Much more disturbance seems necessary to maintain abnormally high levels of infection by *M. mellificae* than by *N. apis*, as the cyst stage of the former does not appear until 3 weeks after infection (Fyg, 1932; Hassanein, 1952b), so that in summer, infected bees will be foragers that are almost at the end of their lives before they become infective. Infective spores of *N. apis* form after 10 days or less—well within the life span of the bee in summer.

Paralysis

Results of experiments by Burnside (1933) made it appear that adult bees with " paralysis "—dark, greasy-looking, virtually hairless bees, with sprawled legs and wings—had an infectious disease

that was transmitted directly between them. Butler (1943) made similar laboratory tests with the same results, but at the same time he pointed out that a variety of diseases, some non-infectious, and various poisons may produce similar signs. Burnside (1945) made further controlled laboratory experiments which seemed to show that the infectious disease was caused by a filterable virus. About 2% of samples of bees sent to the National Agricultural Advisory Service annually from England and Wales are diagnosed as paralysis, but the proportion that are of the infectious variety is unknown.

Conclusions

The common infections of the adult honeybee are not principal factors limiting the survival and growth of endemically infected colonies that are otherwise normal. But they tend to reach serious proportions when such colonies suffer set-backs. The set-backs are sometimes adventitious, but they are often imposed or aggravated by beekeeping practices. The increasing knowledge of the natural histories of adult bee infections should help to mitigate these actions. An understanding of the striking annual epidemic of EFB, which usually occurs in endemically infected colonies, should produce similar advantages. More epidemiological studies of AFB may be helpful, even though natural control of this disease, once present, seems poor.

Devising prophylactic measures depends on fundamental knowledge of the natural history of the infection concerned. Direct therapy may often be improved and evaluated by such information. Accordingly, the accumulation of fundamental knowledge remains the primary purpose of research on diseases of the honeybee at Rothamsted.

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THE WHEAT BULB FLY, *LEPTOHYLEMYIA COARCTATA* FALL.

A Review of Current Knowledge of its Biology

By

D. B. Long

Introduction

Wheat Bulb Fly has been a pest of wheat and other cereals in Britain for many years (Curtis, 1860; Ormerod, 1882, 1892). Recently its effects on wheat crops have increasingly attracted attention, particularly in 1944, 1945, 1952 and 1953. In 1953 the National Agricultural Advisory Service reported that 60,000 acres of wheat failed, 60,000 acres needed to be patched and more than another 80,000 acres were damaged, and the direct loss at £1,250,000 was estimated (Gough, 1957a, 1957b). At Rothamsted Wheat Bulb Fly has infested winter wheat on Broadbalk since 1925, when a system of fallowing to control weeds was introduced, and its biology has been studied in the Entomology Department since 1953.

Life History

Ormerod (1892) recognised that the fly had only one generation a year and that the infesting maggots came from eggs laid in the soil before seed sowing. Eggs are laid in the surface layers of soil from mid-July until, according to season, September, and unless subsequent ploughing is deep they mostly remain in the top 3 inches of soil (Petherbridge, Stapley & Wood, 1945). The initial development in the egg is completed in 2 weeks (Hedlund cited by Rostrup, 1924; Gough, 1946), but it does not hatch till early spring (January to March). The newly hatched larva can survive without food for at least 5 or 6 days (Gemmill, 1927; Long, 1960a) till it locates a host plant. The larva enters the base of a shoot and spends about three-quarters of its larval life feeding on the central tissues; it then moves to another shoot, possibly on the same plant. It moults twice, once late February–early March and again late March–early April (Gough, 1946). During April and early May larvae finally leave the plants and, after a prepupal stage lasting some days, pupate nearby in the soil about $\frac{1}{2}$ inch below the surface (Gemmill, 1927; Gough, 1946). The flies emerge in early to mid-June, and copulate about 3 weeks later. During this period the flies remain near the wheat crop from which they emerged, but the female flies then gradually disperse over a wider area during the oviposition period, when eggs are laid in bare soil of fallows or beneath potatoes and other root crops.

Distribution

Wheat-Bulb Fly occurs in central and northern Europe, in the Low Countries and Germany, Denmark, Sweden and Norway and

parts of Russia. Its southern limit in Europe borders on regions with more than 5½ months with temperatures during the day higher than 9° C. (Schnauer, 1929). In the British Isles Wheat Bulb Fly is mostly confined to the eastern side of England and Scotland; the distribution is roughly bounded by the 30-inch rainfall isohyet (Thomas, 1948), which also bounds the wheat-growing area; distribution may thus be explained on a basis of cropping and rotations (Gough, 1957b). Areas where it is most important are Isle of Ely, Lincs., Notts., Hunts., W. Suffolk, Essex, Beds. and Cambs. in England, and Mid- and East Lothian in Scotland.

Host Plants

Wheat, rye or barley can all be infested when sown in autumn or winter, but oats are immune (Gemmill, 1927). In experiments larvae did not develop in oats, and relatively few reached maturity in barley (Gough, 1946).

Larvae were found in some coarser wild grasses, and flies were bred out of Couch Grass, Fiorin, Common Bent Grass, Meadow Fescue, Meadow Grass and Rough Meadow Grass (Gough, 1946; Stokes, 1955). Larvae attacked seven other species, including Cocksfoot and Wall Barley, but no flies were bred out of them. Couch Grass appears to be a common wild host, and is more attractive than wheat to young larvae, which also develop more quickly in it (Gemmill, 1927; Raw & Stokes, 1958). Barley, Common Bent Grass, Rye, Meadow Fescue and Meadow Grass are all less attractive than wheat in that order.

Biology

The egg

The egg is whitish cream, about 1·3 mm. long and 0·4 mm. wide and weighs 0·08 mg. In summer most embryos are fully formed within 14 days of laying. Embryos dissected out of the egg shell show movements (Gemmill, 1927) but no locomotion, and they cannot infest plants even when inserted in shoots (Way, 1956).

The fully formed embryo has a diapause of about 6 months, about 100 days of which are obligatory (Way, 1956), so that eggs normally hatch in the first 2 or 3 months of the year; Morris's (1925) statement that some emerge in autumn has not been confirmed. After its initial development the embryo requires a period at a temperature below 12° C.; the diapause ends most rapidly and the death rate is smallest at about +3° C. (Way, 1959). A peculiarity is that whereas diapause ends at −6° C. more slowly than at +3° C., temperatures around −20° C. shorten the egg stage from 6 months to 3. Below this temperature the eggs may freeze and die (Way, 1957, 1960). When diapause is complete the eggs soon hatch when the temperature is above freezing, but not otherwise. Thus, hatching can be much delayed by prolonged frosts.

Rostrup (1924) and Gough (1946) observed that eggs buried deeply in soil also hatch late: as such eggs are unlikely to experience temperatures as low as those at the surface, diapause may be prolonged.

Unless kept in a saturated atmosphere or in contact with water,

the egg loses water irrecoverably; desiccation during the long period in the egg stage is a hazard, and in dry years may affect survival. Water constitutes 60% of the egg; at 77% relative humidity in summer temperatures one-fifth of this is lost in 13 days, and half the eggs die (Long, 1955). Loss of water is primarily restricted by the physical structure of the egg shell; damage to its surface increases water loss, which also increases 2 or 3 days after treatment with poisonous substances such as cyanide and TEPP. Infertile eggs from non-mated females lose water nearly twice as fast as fertile eggs. Water loss is often accompanied by a partial collapse of the shell: many eggs from field soils show this, but most are still viable.

The Larval and Pupal Stages

Cultivation may bury the egg deeply, and Gough (1946) showed that plants can be infested from eggs buried 18 inches in sandy soil. When larvae hatch they move steeply upwards to the top layer of the soil, where they respond to exudate (Stokes, 1956) produced by the part of the wheat shoot beneath the soil (Long, 1958e). Larvae are also attracted by exudate from the root zone near the base of the plant, but this appears to confuse rather than help the larvae in finding a shoot. Guttation droplets from the leaf tips are also attractive, and on running down to soil level these may reinforce the attractiveness of shoot exudate.

Larvae tend to attack uninfested plants (Long, 1958a), and should an attacked plant be selected, they seldom attack a shoot already infested. The exudate from infested shoots or plants is presumably less attractive than that from healthy plants. Occasionally more than one larva infests the same shoot, but they then usually all die. The attractiveness of the exudate is decreased by boiling and destroyed by drying at high or low temperature. The exudate is probably protein, which is destroyed fairly rapidly in the soil (Long, 1959).

In pots larvae buried 9 inches below the surface established an infestation most successfully in sandy soil, less so in clay soil and nearly failed in a peaty loam (Long, 1960a). Highly acid soils may interfere with infestation; the failures in peaty loam were possibly due to the soil impeding larval movement rather than to adverse pH. Much of the wheat in the United Kingdom is grown in peaty soils where heavy infestations frequently occur, but most of the eggs remain in the top 3 inches of soil after cultivation (Petherbridge, Stapley & Wood, 1945), so the larvae have to travel less than in the pot experiments to reach the host plant. In clay soil newly hatched larvae can move at least 21 inches before infesting a plant, and moving from plant to plant can travel at least 33 inches during their lifespan. After leaving a shoot, larvae can detect adjacent plants, and they move along the rows of plants rather than across them. Nevertheless, many larvae may die because they fail to infest another shoot at this stage.

The larva enters the shoot through a very small hole bored at the base and spirals upwards for 1–2 cm. before descending into the central leaf cylinder. As the larva destroys the growing point of

the shoot and the bases of the central leaves, the damaged tissues turn brown. The larva grows relatively slowly in its first shoot, and, according to the size of the shoot, moults once or twice before moving out to infest another. Young larvae generally restrict their feeding to the white tissue of the shoot below ground, but older larvae feed more voraciously and may also attack the central green tissue above ground. When the base of the central shoot is first severed it is surrounded by exuding plant sap and remains green at first, but turns yellow after several days. This process may be hastened by dry weather, and apparently healthy wheat crops reveal a heavy infestation by shoot centres turning yellow with the onset of dry weather.

Full-grown larvae vary considerably in size and form pupae about 6 mm. long and 2 mm. wide within a weight range of 5–16 mg. The pupae are a light yellowish brown when first formed, but darken with age.

The Adult Stage

Many Wheat Bulb Fly problems concern the adult insect, e.g., its sex ratio, its food during the many weeks spent in the crop and its fate by death or dispersion. Why does the fly, unlike other Anthomyids, lay its eggs in soil and not on the host plant? An answer to this might enable us to prevent oviposition in fields about to carry wheat.

Techniques

Three different techniques were used to study emergence, life-span, behaviour and dispersion of each sex in the field: sweeping the crop with a hand net, using a large cage enclosing a known fly population on a region of standing crop and releasing marked flies. Unsuccessful attempts were also made to develop a standard trapping technique using sticky traps, water traps and suction traps.

Net sweeping can be done only in daylight under limited weather conditions. It takes much time, requires many people to sweep several different places at the same time, is difficult to standardise and the results of sweeping different types of crops cannot be compared quantitatively. Sweeping also disturbs the environment, so it must not be done too frequently (DeLong, 1932; Gough, 1946; Long, 1958b).

In the " field-cage " studies the number and distribution of individually marked flies could be observed directly over periods without touching them and without greatly disturbing the environment. Thus, with a fly population of known size and age, the technique permitted studies on behaviour and length of life (Dobson, Stephenson & Lofty, 1958; Dobson, 1959; Dobson & Morris, 1960). Differences between the effect of environment inside and outside the cage are difficult to assess.

Field-cage experiments cannot provide direct information on dispersal, so observations were made on marked flies released in the field. Flies were first labelled by feeding them sugar solution containing radioactive phosphate (^{32}P) (Long, 1958b), but later they were marked individually with paint.

Emergence and lifespan

Males emerge consistently 4–5 days before females and over a shorter period (Gemmill, 1927; Dobson, Stephenson & Lofty, 1958; Long, 1958b). Most of the males and females emerge in the first half of the emergence period. Sexes are produced in equal numbers and probably live more than 30 days; males die sooner, and their maximum observed life-span was 55 days compared with 75 days for females. Flies emerging later in the season seem not to live as long as those that emerge early (Dobson & Morris, 1960).

The daily rhythm of behaviour and dispersal

The flies in a wheat crop have a daily rhythm of activity. In early morning, when temperature is low, many may crawl up and rest on stalks and ears. As temperature rises, they become more active and flit between stems. In temperatures above 12°–13° C. they fly from the crop, and the number at the top of the crop decreases rapidly and reaches a minimum by midday. During the afternoon, whether temperature falls or not, the number of flies at the top of the crop slowly increases and reaches a maximum just before nightfall.

Field-cage studies showed that these movements result from two periods of high activity during the day, one in the early morning and the other in the evening. Dobson (1959) related the periods of maximum activity to low light-intensities of less than 50 joules/cm.^{2} occurring at those times.

The fly is small, about 8 mm. long with a wing span of about 15 mm.; the female is dun coloured and the male somewhat darker. They fly fairly fast and their movements above the crop cannot be followed by eye, so that an airborne population is not noticed. However, because flies are less active in the middle of the day, flight above the crop or dispersal probably fails to explain why fewest are observed on the crop at midday. Flies resting on the lower parts of stems and on undersurfaces of leaves, both in the crop and nearby herbage, would not be seen, and sweeping shows the female to be at a lower position in the crop for a period in the middle of the day.

Activity is minimal during darkness, when flies rest head-upward in contrast to the head-downward posture of daytime. The possible relation between low light intensity and high activity, however, is interesting, as it may explain other observations: Gough (1946) describes active male flies congregating in the afternoon in the shade of trees, and reaction to light may partly explain the disproportionately large number of flies that often occur on the shadier north-east borders of the crop. Miles & Miles (1955) considered such a distribution could be attributed to attractants released from cultivated damp soil, but this seems unlikely, as local aggregations would then be expected on the upwind and not the downwind edge, as has been observed in both wet and dry weather.

The two widely separated periods of maximum activity will influence the timing of the fly's other activities, such as dispersal and oviposition. Experiments with marked flies showed that flies may spend periods of a day or more in a given area of crop, but they do

gradually disperse into other areas. Males tend to remain on or near the crop and may be found in loose aggregations relatively late in the season. Females, however, disperse more readily and may be found in surrounding fields and hedgerows. Thus the total fly population tends to exist as a series of localised concentrations centred around infested fields until harvesting and the distribution of subsequent larval infestations indicate that dispersal is not over great distances. The density of these concentrations steadily decreases from June until harvesting as flies die and others disperse. Light winds seem not to affect either flight or dispersion, but winds above 14 m.p.h. do decrease flight, and a gale decreased a local concentration by 75% (Long, 1958b).

Daily rhythm of oviposition

Direct observation on oviposition in the field is difficult. Hedlund (cited by Rostrup, 1924) concluded from field observations that it happens in the evening, and in the laboratory egg-laying was restricted to the afternoon and evening, with maximum laying in the 2 hours before nightfall (Long, 1958d).

Keeping flies in the dark for 24 hours did not affect their behaviour, and laying was also unaffected by changes in temperature between 15° and 25° C. Exposure to light, however, affects the time of laying, and the oviposition rhythm disappears by the 4th day in continuous light.

Egg batches are laid at intervals of 4–18 days, and each batch is laid over a period of 1–6 days. The total number of eggs laid over successive days may exceed the number of ovarioles, and as these only bear one mature egg each at a time, eggs can develop rapidly (within 24 hours) inside the female. Thus, because there are intervals when eggs develop only slowly and none is laid, the effect of light on the time of oviposition is more likely to be directly related to the daily rhythm of activity, with its suggested association with changes in light intensity, than to the processes governing egg maturation. In the evening, when the soil is still warm, activity is maximal on the crop, so if any eggs are to be laid they are to be expected then in the nearest suitable site to the infestation. Gough (1946) considered that each mature female laid, on average, up to 32 eggs, but Long (1958d) estimated the number to be nearer 50.

Adult food

In the field flies often probe drops of water on wheat plants, flowering ears, nectar-secreting flowers of various weeds and dead flies, but there is no proof that they are feeding. However, wheat may be a source of food, as a crop in flower can influence the distribution of the fly population (Long, 1958b). Wheat comes into flower just after the flies emerge, but flowering lasts only about 10 days and a supply of food is needed throughout the 4-week period when the sexes are maturing. Thus the problem of nutrition in the field lies behind the nutritional requirements for maturation of sex cells.

In the laboratory various foods were tried, principally sugars, dried or condensed milk, meat extracts or blood (Petherbridge, 1921;

Gemmill, 1927; Gough, 1946; Bardner & Kenten, 1957). Diets in the crop were simulated by offering fresh wheat pollen, washings from leaves and stems kept in the dark at 100% relative humidity to encourage the production of plant exudates, and water, but all failed to keep flies alive for more than a few days, and no eggs matured (Long, 1958a). Probing flies are sensitive to sugars (Long, 1957), which appeared to be essential for survival together with a protein for maturation of eggs. Thus, females on a diet of honey, old bee pollen and water survived longest and laid the most eggs. It was suggested that flies disappeared in the middle of the day because they were foraging for food, but Dobson & Morris (1960) noted that flies lived long and matured normally in a field cage which contained very few plants except wheat and grasses. Thus the problem of nutrition remains unsolved.

Oviposition sites

(a) *Type of soil and previous crop.* Severe attacks by Wheat Bulb Fly are of two types: those on heavy land after a fallow or bastard fallow during the egg-laying period, and those on lighter land (sands, silts and peat) after potatoes or other root crops (Gough, 1947, 1957a). Apart from this, differences in the degree of attack can frequently be related to the effect of the previous crop on oviposition. Attacks in different localities and on different soils throughout the wheat-growing areas were severest after fallows and potatoes, less after peas and roots and least after cereals, beans and pastures (Gemmill, 1927; Petherbridge, 1944; Gough, 1947, 1949). Gough (1957b) states that in potato-growing areas the likelihood of damage by Wheat Bulb Fly is greater the higher the proportion of land under potatoes. On the relatively uniform clay loam of Rothamsted the severity of attack is also related to the previous crop: thus the heaviest attacks follow fallows or soil ploughed during the egg-laying period; smaller infestations follow low crops such as potatoes which do not form a dense, continuous cover; small attacks follow tall crops, such as beans and cereals, and least severe are those after the mat cover of grass (Long, 1957b, 1958c).

This may possibly be explained by the behaviour of the fly, which usually does not descend more than 18 inches into the crop: tall crops may thus discourage oviposition. The effect of the previous crop, therefore, might be interpreted in terms of the opportunity for the fly to come into contact with the soil. However, soil attracts the flies, which alight on large areas of bare land, areas unknown before agriculture. A tall standing crop influences the path of flight down to bare soil and reduces egg-laying for a horizontal distance up to twice its own height. Crop height may also affect flight behaviour, for no more eggs were laid in wheat that had been drastically thinned than in a normal stand (Long, 1959).

(b) *Effect of soil treatments.* Some of the severest attacks on Broadbalk field were in the dung plot, and severe attacks have been noted in other fields on plots treated with dung up to 5 years earlier (Raw, 1954; Long, 1958c). These observations were made after dry summers, and Raw suggested that ovipositing flies were attracted by organic residues in the soil. He failed to demonstrate this ex-

perimentally (Raw, 1955), perhaps because his experiments were in the wet summer of 1954.

Rostrup (1924) observed that cultivation appeared to affect oviposition, and Gough (1947) stated that compacted cloddy soil under potatoes appeared to be preferable to light open soil under a weed cover. Extensive experiments, both in micro-plots and on commercial farms (Raw, 1955, 1960), showed that heavier infestations follow a fallow with rough tilth and cultivations in the egg-laying period than follow smooth tilth and no cultivation. Raw suggests that a rough tilth favours oviposition because it exposes more surface of soil with more possible oviposition sites in cracks and crevices, and the number of sites is increased by cultivation. Flies lay eggs mainly in fallow land on heavy soil and in potato crops on light soil, possibly because light soils are seldom fallowed and cultivated areas leave a smooth tilth. Furthermore, uncultivated heavy soil frequently " pans ", which might render oviposition more difficult.

Mortality

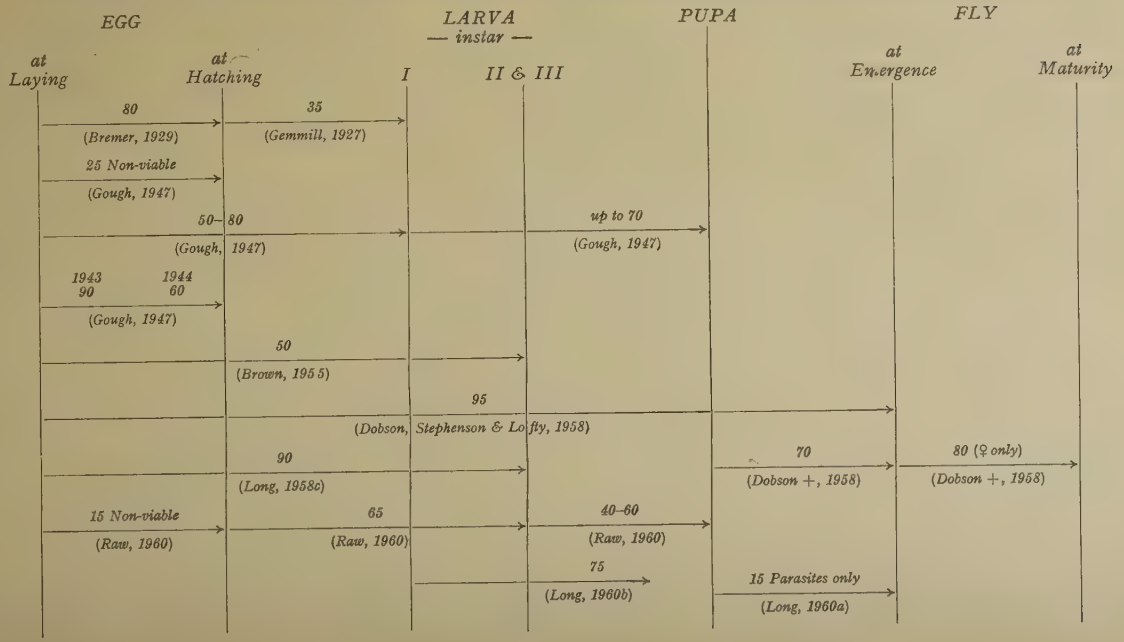
Bremer (1929) recorded that 80% of eggs were empty or dead by October, and Gough (1947) observed that many disappeared in 1943 but not in 1944; Raw (1960) found that few had disappeared by February. The number of eggs that die probably depends on their position in the soil, on seasonal factors and on the abundance of predators and pathogenic organisms. In a dry season exposed eggs soon shrivel and die; in a wet season they may be retarded or die when soil becomes waterlogged. Fungi cause some losses, but the large autumnal losses reported by Bremer (1929) and Gough (1947) were probably caused by predators; Bardner and Kenten (1957) suggested that species of Collembola, Staphylinid beetles and mites are responsible. Infertile eggs were estimated as between 15% (Raw, 1960) and 25% (Gough, 1947).

The larva is vulnerable between hatching and entering its first shoot. The type of soil and the distance between the egg and the plant is most important: thus 73% of eggs died in 9 inches of sandy soil, but 98% in 9 inches of peaty soil. Deaths are more in acid soils below pH 5 (Long, 1960). Raw (1954) suggested that the number of shoots available for infestation is very important; it affects the survival both of newly hatched larvae and of older larvae moving from shoot to shoot. The number of shoots is often directly related to seed rate and so is the number of surviving larvae (Long, 1958a; Raw, 1959).

When the number of larvae approaches the number of shoots mortality is slightly increased by two or sometimes more larvae entering the same shoot and dying as a result: Gough (1946) found that up to 3% of shoots contained more than one larva. Larvae move mostly in the surface layers of soil, and weather probably affects their survival there, as they are liable to dry up quickly and die; partially dehydrated larvae, however, drink readily (Mellanby & French, 1958) and might be kept alive by a shower of rain. Estimates of deaths of larvae are 70% (Gough, 1947) and 75% (Long, 1960b), which may partly be attributed to losses associated with later larval movement. Within the plant, larvae appear to be

Table 1

Estimates of approximate percentage mortality between different stages in the life-history of Wheat Bulb Fly



remarkably free from parasites or predators, although a few may be attacked by pathogenic organisms. Throughout the larval period, most deaths probably happen because of failure to locate and infest the host plant.

Some pupae may be destroyed by parasites and predators. Of 4,800 pupae examined 10% were parasitised: 8% by Staphylinids *Aleochara bipustulata* L. and *A. inconspicua* Aubé (Dobson, 1960). Pupae are also parasitised by Hymenoptera, notably a cynipoid parasite (*Trybliographer* sp.) and occasionally the Ichneumonoids *Phygadeuon oppositus* Thoms. and *P. trichops* Thoms. (Bardner & Kenten, 1957; Dobson, 1960). Various soil arthropods, including *Amara* sp., attack the pupae. Long (1960b) considered 16% of pupae to be parasitised, and total pupal mortality may exceed this.

Very little is known about predators that attack adult flies, but spiders and dung flies (*Scopeuma* sp.) prey on them (Bardner & Kenten, 1957). Flies are attacked by pathogenic organisms; Gough (1947) observed a few killed by a fungus, presumably *Empusa muscae*. Another fungus from the field, forming a cyst in the abdomen, killed many flies in laboratory cultures (Long, 1956) and, with two other fungi suspected of pathogenicity, were experimentally examined with inconclusive results (Buxton, 1958; Long, 1958a).

Factors affecting mortality at different stages will vary considerably between different localities and different years so that estimates must be interpreted cautiously. Table I summarises existing estimates.

Cultural Control

It was early suggested that Wheat Bulb Fly could be controlled by not sowing wheat after a root crop or a fallow (Gemmill, 1927). However, Gough (1946) pointed out that this is often neither desirable nor convenient, and established (1949), by showing that there is a small permanent population in both wheat after cereal and in areas not ploughed for 30 years, that changes in crop rotation could not eradicate the fly. Other suggestions of Gemmill were to sow after mid-February and lose the advantage of winter-sown wheat, to avoid deep sowing so as to encourage tillering and to clear away couch grass. Rostrup (1924) advocated trap fallows sited near infested fields and later planted with a non-host crop. In less-intensive wheat-growing areas, field results (Long, 1958b, 1958c) suggest that attacks can be decreased by siting susceptible crops for the following year well away from currently infested fields.

Wheat which is well established by the time infestation occurs is best able to withstand attack, and so early sowing has been advocated. This is not always possible, and on heavy land it may encourage black grass and increase the risks of a winter-proud crop, eyespot and lodging (Gough, 1957a). Early sown crops bear more tillers which assist the survival of larvae, so that cultural methods aimed at decreasing the damage in one year may increase the fly population and the risk of future damage (Raw & Lofty, 1959). However, late sowing is to be avoided; and because larva mortality can be greater at low plant densities, Raw (1960) recommends that the seed rate should be kept to the economic minimum for a high

yield and that, if the intended site is fallow, it should have a fine tilth and not be cultivated during the oviposition period.

Effect on Yield

Gough (1947) found that good yields were obtained when 39 and 66% of the plants had been infested in the spring, but with infestations of 79 and 81% crops failed. However, yields are much influenced by other factors, such as season, soil fertility and disease, although the last is seldom serious after a fallow, when Wheat Bulb Fly may be numerous. Therefore Raw & Lofty (1957) and Raw (1960) assessed the effect of attack on yield by direct experiment. Areas of fallow, both at Rothamsted and at farms elsewhere, were covered by fine-mesh terylene screens during the oviposition period, and the larval infestation and yield of these areas were contrasted with those of the surrounding wheat. Yields from small plots of wheat on Pennells Piece at Rothamsted, where cultivation and tilth experiments had altered levels of infestation, were also compared.

The effect of damage on yield depended largely on plant growth in the crop. Thus on Broadbalk, infestations up to 30% of plants did not affect yields of grain or straw. On Pennells Piece plant infestations of 37–81% decreased grain by up to 6 cwt./acre, but at Herkstead Hall and Fowes Farm no decreases were observed with infestations up to 860,000 larvae/acre (equivalent to 73% of plants). Yields of 30·5 cwt. grain/acre were obtained with 81% infestation at Rothamsted and 32·6 cwt./acre with 73% infestation at Fowes Farm. Raw observes that these results show that wheat can withstand or compensate for attack considerably, and suggests that there may be a critical balance between crop failure and recovery.

Forecasting

To forecast attack by Wheat Bulb Fly which would be of value to the farmer, we need to know the expected level of attack by larvae in the spring and the probable effect of the damage on yield. The possibility of basing forecasts on egg counts was studied by Bremer (1929) and by Crüger & Körting (1931), and from their results the amount of damage appeared to be related to egg number. However, the considerable variability in the local distribution of eggs, in viability and in mortality, together with unknown variability in factors affecting mortality of larvae, render such estimates too unreliable in my opinion for practical purposes, and Gough (1947) considered that egg counts would probably be valueless.

Although weather seems to influence outbreaks (Gough, 1947), attempts to find the important factors have failed (Kleine, 1915; Petherbridge, 1921; Rostrup, 1924; Schnauer, 1929; Bremer, 1931), perhaps because the effect of weather on egg laying only was considered, whereas that on plant growth may be the most important.

At present, therefore, there is little hope of making long-term forecasts of attack, but it remains possible to forecast in the spring the possible effect on yield from observations on plant growth and infestation in the field. Simple estimates of larval population do not serve this purpose, as Gough (1947) found a crop failed with a

population of 180,000 larvae/acre, whereas Raw (1960) observed no effect on yield with a population of 860,000 larvae/acre. Gough (1953) lists plant vigour, weather, soil consolidation, date of sowing and soil fertility as determining the effect of the attack.

Crop recovery has two major inter-related factors: the recovery of attacked plants and compensatory growth in adjacent unattacked plants. The size of the plant at the time of attack is obviously important, and, if the attack is very heavy, as in 1953, may be critical. Gemmill (1927) suggested that attacked plants tiller more readily than unattacked plants, but such plants are usually retarded (Long, 1960b). However, fewer attacked plants die than was first supposed, for some recover if soil conditions and weather are favourable. The extent of infestation coupled with soil fertility and weather govern compensatory growth in unattacked plants, and the relative numbers of attacked and unattacked plant at different stages of the infestation must be considered. However, the availability and size of plant shoots appear to determine both larval growth and mortality, and so to influence the course of the infestation. Thus the close study now in progress of the interaction between the development of infestation and associated plant growth may reveal factors which will make possible more accurate forecasts of effect of infestation on yield.

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THE EXHAUSTION LAND SITE

An Account of Experiments made before and during the Period of Soil Exhaustion

By

R. G. Warren & A. E. Johnston

The Exhaustion Land site is a strip of 2½ acres of arable land at the north end of Hoosfield and derived its name from the unmanured cereal cropping which began in 1902 to measure the residual effects of manures that had been applied in previous experiments. From 1852 to 1902 Lawes and Gilbert used the site for a succession of three experiments. The first, which lasted only 4 years, was a test of the Lois Weedon system of husbandry and was followed by a 20-year wheat experiment consisting of a few of the Broadbalk fertiliser treatments. In the last 26 years before the exhaustion period began there was a manurial experiment on potatoes.

The " Lois Weedon " Plots at Rothamsted, 1852–55

In 1849, during an agricultural depression, the Rev. Samuel Smith promised, in a pamphlet entitled *A Word in Season to the Farmer*, a profit of £4–£6/acre to those who adopted his system of growing wheat year after year without manure. The system, devised and employed by Mr. Smith on the heavy land portion of his 12-acre farm at Lois Weedon, Towcester, Northants, was not continuous wheat as on Broadbalk (until 1925), but was a succession of wheat and fallow strips across the field so that only half the area was in wheat each year. Each strip was 3 feet wide, was sown with three widely spaced rows of wheat at the low seed rate of 1–2 pecks (15–30 lb.)/acre and was cropped and fallowed in alternate years. An essential feature of the system was the intensive cultivation of the strips when they were in fallow, during which the subsoil was broken up and allowed to weather before it was mixed with the surface soil. The results from this system of growing wheat on the heavy land part of the Lois Weedon farm are summarised by Mr. Smith in his book *Lois Weedon Husbandry* (London, James Ridgway, 1856):

> " The ten years' average from this moiety of the acre has been thirty-four bushels; a very high average on any plan from a whole acre. And here, too, therefore, the proverb holds good —The half is more than the whole."

Lawes is most widely known in connexion with superphosphate and experiments testing the effects of different manures on individual crops grown continuously on the same land. However, Lawes and Gilbert were also interested in crop rotations, and in 1851 they began preparations for some " Lois Weedon " plots at Rothamsted on the site at the north end of Hoosfield. At the same time they also started on 1 acre of land adjoining the " Lois Weedon " plots a com-

parison of wheat after fallow for which normal methods of cultivation were to be used and the crop grown without manure. This comparison developed into a long-term experiment, known as the Alternate Wheat and Fallow Experiment. On the " Lois Weedon " plots Lawes and Gilbert followed the operational details as published by Mr. Smith. The fallow strips were, in fact, trenched to 14 or 15 inches.

The " Lois Weedon " plots failed to give the good results that Mr. Smith obtained on his own farm. Not only were yields lower than on the Alternate Wheat and Fallow Experiment but also lower than those of the continuously cropped unmanured plot on Broadbalk. The " Lois Weedon " experiment on Hoosfield was ended after the harvest of 1855. During the course of the experiment half the land had been trenched once and the other half twice.

Winter Wheat Experiment 1856–74

Lawes and Gilbert were sure that the low yields on the " Lois Weedon " plots at Rothamsted were caused by the low seed rate prescribed for the system, but nevertheless they began a search for the reasons that would explain the success of the system at Lois Weedon and the failure at Rothamsted. Smith suggested that a deficiency of minerals was one of the causes of the failure on Hoosfield at Rothamsted, but Lawes and Gilbert thought that the amount of assimilable nitrogen in the soil was more important. Broadbalk up to this time had demonstrated the greater importance of nitrogen for wheat. To confirm this for the Hoosfield soil they started in 1856 to test some of the Broadbalk manurial treatments on the site of the Lois Weedon strips. There were four plots, each containing an equal proportion of the trenched fallow and stubble ground, and the four treatments selected were unmanured, ammonium salts only, minerals only and ammonium salts with minerals; the fertiliser rates were the same as those of plots 5, 10 and 16 on Broadbalk, 1855. The land was prepared in the autumn of 1855 in the normal way, manures including the ammonium salts were applied in the autumn, and winter wheat sown at about 2 bushels/acre. On the north side of the plots there was another unmanured strip. This was narrower than each of the four plots and later formed part of plots 1 and 2 of the potato experiment, 1876–1901.

The results of the first year of this wheat experiment were similar to those for the comparable plots on Broadbalk and led Lawes and Gilbert to make the following statement in their account of the Lois Weedon System (*J. R. agric. Soc.* **17** (1st Series), 1856, p. 591):

> " Hundreds of other experiments, and the whole range of recorded agricultural experience, conspire to show, that in ordinarily cropped and cultivated soils, the available mineral supplies are generally in excess relatively to the available supply of nitrogen of the soil and season, in the case of the wheat crop: in fact that, excepting in cases of very special and unusual exhaustion of the mineral or soil-proper constituents, the direct supply of them by manure for wheat does not increase the crop in any practicable and agricultural degree, unless there be a liberal provision of *available and assimilable nitrogen in the soil.*"

The results showed that a supply of " available " nitrogen was more important than deep cultivation on the Hoosfield soil but did not explain the success of the system at Lois Weedon. Lawes and Gilbert never offered a satisfactory solution to this problem, for they drew no conclusions from their figures for total nitrogen in the soil and did not supply any figures to indicate the amount of " assimilable " nitrogen in the soil. It can be said now that, as the land at Lois Weedon had been old grassland it probably contained more " available " nitrogen than the Rothamsted soil. The turf had been pared off and used on other land for root crops, but the remaining soil evidently contained ample mineralisable nitrogen, because Smith made the following comment in his book:

> " This fresh-broken up land for several years produced over-luxuriant crops and very frequently the usual evil results."

The wheat experiment on Hoosfield continued until 1874. The results for the first 6 years (*J. R. agric. Soc.* **25** (2nd Series), 1864, p. 449) continued to resemble those on Broadbalk, but in later years the yields of wheat in the Hoosfield experiment were lower and the response to nitrogen less. The average yields for 5-year periods from 1856 to 1870 for Hoosfield and Broadbalk are given in Table 1.

TABLE 1

Yields of wheat on Hoosfield and Broadbalk, 1856–70

Five-year averages of dressed grain, bushels/acre

Years	Treatment							
	Unmanured		Ammonium salts		Minerals		Ammonium salts and minerals	
	H *	B	H	B	H	B	H	B
1856–60 ...	16	16	29	24	18	20	37	36
1861–65 ...	10	15	18	28	14	16	36	42
1866–70 ...	10	13	13	24	13	15	20	32

Fertiliser Dressings per acre:

Ammonium salts—
200 lb. ammonium sulphate
200 lb. ammonium chloride

Minerals—
200 lb. potassium sulphate †
100 lb. sodium sulphate
100 lb. magnesium sulphate
Superphosphate prepared from 200 lb. calcined bone and 150 lb. sulphuric acid.

* H = Hoosfield; B = Broadbalk.

† 300 lb. potassium sulphate, 200 lb. sodium sulphate in the three years 1856–58; the quantities were then reduced as they were on Broadbalk.

Lawes and Gilbert did not comment on the difference between the behaviour of the Broadbalk and Hoosfield wheat plots during the years 1861–70. A note in the record book of the Hoosfield experiment, however, stating that the land was very foul with weeds in 1870, may partially explain the lower yields. The site was fallowed in 1871 and 1872 and was again cropped with wheat in 1873 and in 1874, the first of the two crops was unmanured. For the 1874 crop the minerals were not given and the ammonium salts were *withheld until the spring* and then applied at only *half the usual rate.*

The yields were higher than those on the corresponding plots on Broadbalk and the response to nitrogen greater. It is worth noting here that the time of applying ammonium salts on Broadbalk, except Plot 15, was changed from autumn to spring for the 1878 crop and altered again for the 1884 crop to a divided dressing, part being given in autumn and part in spring. Starting in 1873, Plot 15 received all its ammonium salts in spring, then for the 1878 crop all the nitrogen was applied in autumn, the current practice. The Hoosfield experiment ended with the 1874 crop, and the land was fallowed in 1875.

Potato Experiment 1876–1901

In 1873, after a virulent attack of potato disease in the previous year, a special committee of the Council of the Royal Agricultural Society initiated investigations on the potato crop. As a part of these investigations a questionnaire on the cultivation of the crop was sent to leading growers. In the report on the questionnaire by Jenkins (*J. R. agric. Soc.* **10** (2nd Series), 1874, p. 475) one feature which must have interested Lawes and Gilbert was the considerable variation in the manuring of the crop, though many growers did use farmyard manure. A few years earlier Voelcker had published the results of several experiments on the manuring of potatoes in the *Journal of the Royal Agricultural Society* [**3** (2nd series), 1867, 500; **6** (2nd Series), 1870, 392; **7** (2nd Series), 1871, 365]. Voelcker concluded that good crops of potatoes could be grown on light land comparatively cheaply by using fertilisers consisting of ammonium sulphate, superphosphate and potassium sulphate. On heavy land " in good agricultural condition " he considered that ammonium sulphate could be omitted or less used and that, on this type of land, sodium nitrate may be more effective than ammonium sulphate.

Lawes and Gilbert began their manurial experiment on potatoes in 1876, and although one of the objects was to find whether the type of manuring was related to the amount of disease in the crop, the main purpose of the experiment was to obtain information on the nutrient requirements of the potato crop. The wheat site was extended about 12 links on the north side to make the fifth strip nearly the same width as the remainder, and the five strips were then halved. The new plot numbers of the potato experiment and the corresponding wheat plot numbers, together with the manurial treatments, are shown opposite one another in Table 2.

TABLE 2

Wheat Experiment	Potato Experiment	
Plot 1 (P, K, Na, Mg)	Plot 9 (P)	Plot 10 (P, K, Na, Mg)
2 (N, P, K, Na, Mg)	7 (N, P, K, Na, Mg)	8 (N*, P, K, Na, Mg)
3 (N)	5 (N)	6 (N*)
4 (O)	3 (dung, P)	4 (dung, N*, P)
5 (O)	1 (O)	2 (dung)

N = Ammonium salts.
N* = Sodium nitrate.

The fertiliser treatments from the wheat were continued in the potato experiment, and new treatments with farmyard manure and sodium nitrate were added.

The results of the first 12 years of the experiment were given in a lecture by Gilbert at the Royal Agricultural College, Cirencester, in 1888 and published in the *Agricultural student gazette*, New Series, 4, part 2. The average yields during the first and second 6-year periods are given in Table 3, together with the average yields during the remaining years of the experiment, 1888–1901.

TABLE 3

Average annual yields of potatoes grown continuously on Hoosfield 1876–1901

Plot	Treatment	Years 1876–81	1882–87	1888–1901
1	Unmanured	2·28	1·69	0·84
5	N	2·51	2·07	1·19
6	N*	3·20	2·04	1·69
9	P	3·98	3·35	1·91
10	P, K, Na, Mg	4·14	3·39	2·17
7	N, P, K, Na, Mg	7·52	5·94	4·12
8	N*, P, K, Na, Mg	7·78	5·52	4·38
2	F.Y.M.§	5·23	3·05	1·48
3	F.Y.M., P †	5·58	4·25	4·62
4	F.Y.M., N*, P ‡	7·11	4·01	4·74

Fertiliser rates per acre:

N	200 lb. ammonium sulphate + 200 lb. ammonium chloride
N*	550 lb. sodium nitrate
P	1876–1896 3½ cwt. of superphosphate
	1897–1901 400 lb. basic slag
K	300 lb. potassium sulphate
Na	100 lb. sodium sulphate
Mg	100 lb. magnesium sulphate
F.Y.M.	Farmyard manure 14 tons

§ 1876–81, farmyard manure: 1882–1901, unmanured.

† 1876–82, farmyard manure and superphosphate, 1883–1901, farmyard only.

‡ 1876–81, farmyard manure, sodium nitrate and superphosphate; 1882, farmyard manure and superphosphate: 1883–1901, farmyard manure only.

Yields from different treatments must be compared only in the same period, as the variety of potato grown changed during the experiment. Changes were also made in the three farmyard manure treatments. Further, in this experiment with only a few plots and with each treatment represented by one plot, the results from the single nutrient tests (plots 5, 6 and 9) do not give useful information on the requirements of the potato crop. It is also necessary to mention that the yields of plot 9 (P) may be misleading, at least for the early years, because it received P and K fertilisers each year during the preceding experiment on wheat. The wheat crops probably used not more than one-quarter of the added K and left appreciable residues in the soil. The best information is derived from comparing the yields on the plot which received minerals only (10) with those of plots that had minerals and nitrogen (7 and 8) or had farmyard manure (2, 3 and 4). In the first 6 years of the experiment the full complement of fertilisers gave yields above the average for the country and above the yield obtained by farmyard

manure alone. Both forms of fertiliser nitrogen, ammonium sulphate and sodium nitrate, at 86 lb. N/acre on plots 7 and 8 did equally well and produced about 3·5 tons more tubers per acre than the minerals alone (plot 10). The yields on the three farmyard manure plots for the same period indicate that the farmyard manure contained much less available nitrogen than was supplied by the complete fertiliser treatments. Adding superphosphate to the farmyard manure increased the yield by only $\frac{1}{3}$ ton, whereas adding superphosphate and sodium nitrate gave nearly 2 tons more tubers per acre. Although the experiment showed that the 14 tons of farmyard manure was more deficient in nitrogen than phosphorus, it provided no evidence on the potassium status of the manure. In the second 6-year period the complete fertilisers continued to give higher yields than farmyard manure, but in the last 14 years the average yield from farmyard manure was 0·4 ton/acre more than from the complete fertilisers.

The determination of the amounts of nitrogen, phosphorus and potassium in agricultural crops was an important part of Lawes' and Gilbert's investigations. The large differences they found between the N, P and K contents of a crop and the amounts in the manures applied to the crop led them to make single plot tests to measure the effect of the unused nutrients on succeeding crops. In several of their experiments (e.g., Broadbalk, Hoosfield barley and Park Grass) a manurial treatment was discontinued but the land was cropped as usual. The three farmyard manure treatments in the Hoosfield potato experiment were modified to produce further information on the effect of residues, and they published several papers on the valuation of unexhausted manure, their principal concern being with the cash value of manurial residues from different feeding-stuffs. In the last paper (*J. R. agric. Soc.* 8 (3rd Series), 1897, 674) they gave the following conclusions from the Rothamsted experiments on the effect of manurial residues on succeeding crops:

> 1. Heavy and repeated dressings of organic manures must be given before effective residues are built up in the soil. Plant nutrients are released only slowly from the residues, more slowly in heavy soils than in light ones. Three-quarters of the increased yield of barley given by the farmyard manure comes from nitrogen in the residues.
>
> 2. The use of inorganic N fertilisers over long periods may give residual effects because the crop residues left in the soil are increased. For wheat the effect is small.
>
> 3. A considerable portion of the P and K added as fertilisers is fixed in the soil and is only slowly available to subsequent crops.

The Exhaustion Land Experiment 1902–58

After Lawes died in 1900 and Gilbert in 1901, Hall decided to end the potato experiment because the physical condition of the soil that had not received farmyard manure was poor and unsuitable for potatoes.

At the end of the wheat and potato experiments the plots on the Exhaustion Land site had received the following treatments:

Number of dressings each plot received, 1856–1901*

Plot no.	1	2	3	4	5	6	7	8	9	10
Treatment:										
Farmyard manure	—	6	26	26	—	—	—	—	—	—
PK	—	—	—	—	—	—	42	42	17	42
P	—	—	7	7	—	—	—	—	25	—
N	—	—	—	6	44	44	44	44	—	—

Average dressing per acre: farmyard manure 14 tons, superphosphate 3 cwt., ammonium salts 3½ cwt. or sodium nitrate 5 cwt., potassium sulphate 2½ cwt.

* The number of dressings given in *Proc. Fertil. Soc.* 1956, No. 37, have been corrected here to allow for the omission of N in 1 year and PK in 3 years.

The amounts of nitrogen, phosphorus and potassium removed in the wheat and potato crops cannot be estimated precisely, because only a few of the crops were analysed, but a large part of the P and K applied was left in the soil.

After the potato experiment the site was cropped from 1902 to 1940 without manure to measure the duration of the residual effects of the previous manures. The crops were cereals, mainly barley, except on plots 5–10, where there was a soil inoculation trial on clover, 1905–11. The yields of the cereals were recorded regularly only till 1922. Beginning in 1941 the cereals received 2½ cwt./acre of ammonium sulphate each year, and from 1949 the yields were again recorded. Table 4 gives the yields of cereals for three periods, 1902–4, 1917–22 and 1949–53. In 1902, the first year after manuring had ended, barley yielded well (28–34 cwt. grain/acre) on the plots that had previously received farmyard manure or N fertilisers, and the residues from these treatments increased yield by 18 cwt. and 14 cwt. of grain/acre over the unmanured plots. Only the farmyard manure plots, however, continued to yield well in the next 2 years. Hall (*The Book of the Rothamsted Experiments*, 1905) considered that the large 1-year residual effects on the N fertiliser plots came from the increases in crop residues in the soils of these plots rather than from any accumulation of unchanged fertiliser ammonium or nitrate. By 1917 the yields of all plots were very low and the farmyard manure residues gave only small increases in the years 1917–22. The yields of the fertiliser plots, including those which had not received N in the wheat and potato experiments, were also a little higher than those of the unmanured plots, but clover residues probably still remained in these plots and provided a little nitrogen for the cereal crops.

The method of measuring residual effects so far adopted, without new additions of any of the three nutrients N, P, K, gave no information on the contribution to yield of any one of the nutrients contained in the residues; nor did it indicate whether one nutrient in the residues was limiting the effects of the others. In the last period, 1949–53, for which yields are given in Table 4, the effects were restricted to the combined effects of the P and K residues by applying a basal N dressing. The increases in yield were large and were similar for the PK fertiliser residues (10 cwt. barley grain/acre)

TABLE 4

Exhaustion Land 1902–58

Yields of grain cwt./acre 85% dry matter

Plot	Year: Crop: Treatment 1856–1901	1902 Barley	1903 Barley	1904 Oats	1917 Barley	1918 Barley	1919* Barley	1921 Wheat	1922 Barley	1949 Barley	1950 Barley	1951 Barley	1952 Barley	1953 Barley
1	Nil	16·0	4·6	11·1	2·2	3·9	2·2	6·1	5·8	7·6	11·3	13·6	12·9	15·8
2	Nil †	17·1	7·3	10·4	4·3	5·1	3·5	10·1	7·0	10·0	15·1	12·7	10·1	11·8
5	N	28·5	9·2	11·6	2·5	5·6	3·5	10·9	7·8	8·7	12·5	15·2	16·5	17·4
6	N * ‡	30·3	9·0	10·9	3·4	7·6	3·6	12·4	7·9	13·0	14·7	11·2	13·1	14·6
9	P §	16·9	6·4	10·9	3·0	6·9	4·2	15·7	7·5	23·4	24·4	23·4	19·7	20·0
10	PK	12·0	6·2	9·9	3·2	7·1	5·1	15·2	7·0	27·0	26·6	26·4	21·8	21·8
7	NPK	31·0	13·9	14·9	5·6	10·1	5·7	14·1	7·8	23·0	22·2	24·1	21·3	21·4
8	N*PK ‡	32·3	12·6	15·7	5·4	9·2	4·4	14·7	7·8	27·9	26·3	23·8	21·4	20·2
3	F.Y.M.‖	34·2	22·6	26·8	3·5	7·9	5·4	14·1	9·6	26·8	24·2	22·9	23·2	22·4
4	F.Y.M.¶	34·9	21·6	29·6	4·7	7·7	6·0	15·7	9·7	25·9	29·0	25·1	22·8	22·8

* Land fallowed in 1920.
N Ammonium salts.
N* Sodium nitrate.
† Farmyard manure 1876–81, unmanured, 1882–1901.
‡ As ammonium salts, 1856–75; as sodium nitrate, 1876–1901.
§ PK, 1856–75; P, 1876–1901.
‖ Farmyard manure and superphosphate, 1876–1882; farmyard manure only, 1883–1901.
¶ Farmyard manure, sodium nitrate and superphosphate, 1876–81; farmyard manure and superphosphate, 1882; farmyard manure only, 1883–1901.

and the farmyard manure residues (11 cwt./acre). From the large increases on the old farmyard manure plots from 1949 to 1953, compared with the small ones from 1917 to 1922, it was concluded that after a long period of cereal cropping the organic manure residues supplied very little N and that the amounts of available P and K they contained were much more important. Lawes' conclusion that N caused three-quarters of the effect of farmyard manure residues was derived from the results of barley grown on new and relatively new residues. Although the large effects of the farmyard manure and PK fertiliser residues could, when basal N was given, result from the combined effects of P and K, Warren (*Proc. Fertil. Soc.* 1956, No. 37) concluded from the analysis of the crops that the increases with barley resulted almost entirely from P. The analyses of the barley crops also showed that 4–5 lb. more P/acre was removed each year from the PK fertiliser and farmyard manure residue plots than from the unmanured plots. This extra P is a small annual recovery and is equal to only 0·5% of the total P applied either as superphosphate or farmyard manure in the years before 1902. For K the extra amount removed was 15–19 lb./acre, which also represents only a small annual recovery of the K residues.

In 1953 parts of the plots in the west half of the experiment were found to be acid. Differential chalk dressings were applied to the acid area in the winter 1954–55. The whole site continued in barley during the period 1954–56, but in 1957 six crops (barley, spring wheat, potatoes, sugar beet, swedes and kale) were grown in strips across the plots (1, 3, 5, 7 and 9) in the east half of the experiment. The crops were separated by fallow strips which were used for the crops in the next year. Each strip was divided into microplots, and new additions of P and K were superimposed on the old treatments. All plots received a basal dressing of N fertiliser, basal P fertilisers were given when K was being tested and basal K was given where test dressings of P were applied. All fertilisers were applied broadcast except for potatoes where they were put in the bouts. Table 5 shows increases in yields produced by new additions of P and K for the six crops grown in each year.

TABLE 5

The increases in yields given by fresh additions of P and K fertilisers in the Exhaustion Land experiment

Manuring in 1856–1901 period	Increase from new dressing of 1·0 cwt. P_2O_5/acre				Increase from new dressing of potassium fertiliser *			
	No phosphate		Phosphate		No potassium		Potassium	
Year	1957	1958	1957	1958	1957	1958	1957	1958
Barley (cwt. of grain) ...	6	15	0	5	1	0	0	1
Wheat (cwt. of grain) ...	2·5	10	0	2	0	1	0	0·5
Potatoes (tons of tubers) ...	8	8	4	5·5	6·5	5	4	3
Sugar beet (tons of roots) ...	3·5	4·5	0	2	0	3·5	0	0
Swedes (tons)	5	13	0·5	3	0	2	0	0
Kale (tons)	6	6	2·5	2	1	0	2·5	0

* 1·2 cwt. K_2O/acre for potatoes, sugar beet and kale; 0·6 cwt. K_2O/acre for cereals and swedes.

Potatoes, sugar beet and kale responded similarly in both years to new dressings of phosphate where the crops were grown on soil that had received no phosphate from 1856 to 1901 (and none since). The mean yield of sugar beet in 1958 was 50% and of kale 25%

greater than in 1957; potatoes gave similar mean yields in the 2 years. On the same soil the response of swedes to new dressings of phosphate was much greater in 1958 (13 tons/acre) than in 1957 (5 tons/acre); the mean yield of swedes in 1958 was double that obtained in 1957. The phosphate residues from the old manuring were sufficient for full crops of barley, wheat, sugar beet and swedes in 1957, but not in 1958. In 1958 the phosphate residues were equivalent to about one-half to four-fifths of the value of the new phosphate fertiliser dressing for these crops. For potatoes and kale the phosphate residues were inadequate in both years: each year the extra yield of potatoes from the residues was only half as great as the increase given by a new dressing of 1 cwt./acre P_2O_5. For kale the corresponding extra yields in the 2 years were about two-thirds as great as the responses to new dressings.

On soil that received no potassium manuring between 1856 and 1901 (and none since) fresh dressings of potassium fertiliser greatly increased yields of potatoes in both years. In 1957 yield of the other crops was little increased by the fresh dressings of potassium; in 1958, however, new dressings of potassium also increased the yields of sugar beet and swedes, but not of cereals or kale. On the plots that had received potassium between 1856 and 1901 barley, wheat, sugar beet and swedes obtained enough potassium in both years from the residues left in the soil. Potatoes, however, responded well to fresh dressings of potassium in both years, kale gave a moderate increase in yield in 1957 only.

The amount of nitrogen mineralised each year from the farmyard manure residues was not measured. It is thought to have been small in recent years, as the average increase in yield from the residues was only 3 cwt. grain/acre in the years 1917–22, when the residues were supplying adequate amounts of P and K for cereals. The experiments have also not assessed the value of the farmyard manure and PK fertiliser residues for crops such as beans, clover, grass and lucerne. Because the annual rates of extraction of P and K from the residues by crops was determined over a short period only, the total amounts of P and K that may still be taken up from the residues cannot be estimated. The experiments indicate, however, that the percentage recoveries in crops of the P and K added as farmyard manure or fertilisers are greater than is commonly supposed.

ABSTRACTS OF PAPERS

Physics Department

1.1. CURRIE, J. A. (1960). Gaseous diffusion in porous media. I. A non-steady state method. *British J. appl. Physics*, **11**.

Laboratory equipment, capable of modification for use on soils in the field, was built for studying diffusion in porous systems. A simple katharometer employs the exposed element of a thermal milliammeter to measure the instantaneous composition of hydrogen/air mixtures, the most convenient working condition being when 15 mW are dissipated in the hot wire, at which the thermocouple output changes from 0·5 mV in pure hydrogen to 2·5 mV in air. The geometry of the experimental system is simple enough to permit the application of a standard solution of the non-steady state equation for inter-diffusion of two gases; as a check on performance, straight tubes of slightly varying geometry were used to measure the diffusion coefficient of hydrogen into air, and its dependence on temperature. Reproducibility was very good, and within the limits of experimental error the coefficient obtained was the same for 100% H_2 into 100% air, and 60% air + 40% H_2 into 100% air. Measurements at 12°, 20°, 28° and 36° C., fitted $D = D_0 (T/273)^n$, with

$$D_0 = 0{\cdot}651 \text{ cm.}^2 \text{ sec.}^{-1} \text{ at N.T.P.}$$
$$n = 1{\cdot}715.$$

Standard values in the literature are $D_0 = 0{\cdot}611$ (I.C.T., 1929), 0·634 and 0·661 (Smithsonian Physical Tables 1954). The latter reference gives $n = 1{\cdot}75$.

1.2. CURRIE, J. A. (1960). Gaseous diffusion in porous media. II. Dry granular materials. *British J. appl. Physics*, **11**.

The diffusion of hydrogen through cylindrical samples of porous granular materials, 3 inches long and 2 inches diameter, was measured by the non-steady state technique of Part I, and reduced coefficients of diffusion, D, referred to the value D_0 in free air were calculated for over twenty materials with porosity ϵ between 0·18 and 0·98. Results are comparable with those obtained by other methods, and with those for analogous electrical properties of porous media. Replicate determinations on a given sample agree to within 1%, but larger differences, caused by variations in packing, occur between duplicate samples of the same porosity. It is shown theoretically that $D/D_0 = (l/l_e)^2 . f . \epsilon$, where f and l_e/l are factors for non-uniformity of cross-section and the increased length of the tortuous path followed by the gas respectively. The influence on D/D_0 of not only porosity but also particle shape was clearly shown, and so there can be no unique relationship for all materials, as often supposed, between diffusion rates and porosity. The equations of Burger and Bruggeman, both of which include a *particle* shape factor, were tested on the experimental data, and neither is entirely satisfactory. An empirical equation of the form $D/D_0 = \gamma\epsilon^\mu$ fits all materials where $\gamma(\leqslant 1)$ and $\mu(\geqslant 1)$ are constants for a specific type of granular material, and probably represent measures of *pore* shape. Two particle-shape parameters, relative surface area and equivalent settling radius, were measured for a limited number of materials, but at best, only a general trend between these and the experimental values for the Bruggeman shape factor was observed.

1.3. EMERSON, W. W. & DETTMANN, MARGARET G. (1959). The effect of organic matter on crumb structure. *J. Soil Sci.* **10**, 227–234.

Tests on soil crumbs from nearby long-term arable and grassland fields showed that: (*a*) the rate of water uptake by dry crumbs at 98% relative humidity was the same for arable and grassland crumbs and also grassland crumbs pretreated with H_2O_2; (*b*) dry arable and grassland crumbs swell in water to the same amount. The crystalline swelling of the clay in soil crumbs seems unaffected by the soil being under grass. The general arrangement of

the quartz and orientated clay in thin sections of arable and the corresponding grassland crumbs was similar.

Slaking and dispersion tests on the natural crumbs, and on re-moulded crumbs formed by drying from a paste of the natural crumbs, suggested that remoulding does not disperse the clay in either the grassland or arable crumbs, but does break up many of the aggregates between 50 and 2 μ diameter in the grassland crumbs. The natural arable crumbs were so weak that immersion wetting of the dry crumbs alone broke up the aggregates.

1.4. MONTEITH, J. L. (1959). Solarimeter for field use. *J. sci. Instrum.* **36**, 341–346.

A thermopile solarimeter was made from simple materials, with output 5·5 mV cal.$^{-1}$cm.$^{-2}$min.$^{-1}$; resistance 13 ohms; response time 20 s; weight 35 g.; dimensions 4 × 4 × 4 cm. It can be used with a portable millivoltmeter to measure reflexion coefficients, radiation within crops, etc. General equations for solarimeter performance and a simplified theory for the present design give a non-linearity of −0·8% cal.$^{-1}$cm.^{2}min. and a temperature coefficient of −0·12% per degree C. Outdoor comparison with a Kipp solarimeter gave ±0·03 cal.cm.$^{-2}$min.$^{-1}$ as the maximum deviation from the mean response with radiation up to 1·1 cal.cm.$^{-2}$min.$^{-1}$. The standard deviation for thirty observations in bright sunshine and with overcast skies was ±0·002 cal.cm.$^{-2}$min.$^{-1}$. Cosine and azimuth response were improved using a larger instrument of the same design, and comparisons of this with a Kipp solarimeter gave maximum deviation of ±0·02 cal.cm.$^{-2}$min.$^{-1}$.

1.5. MONTEITH, J. L. (1959). The reflection of short-wave radiation by vegetation. *Quart. J. R. met. Soc.* **85**, 386–392.

The fraction of short-wave radiation reflected from agricultural crops was measured from May till September 1958 using two portable solarimetric thermopiles. Maximum reflexion coefficients for grass, lucerne, potatoes, sugar beet and spring wheat were between 0·24 and 0·27. Lower values in the early stages of crop development, and for spring wheat even at maturity, can be correlated with low leaf areas; and mutual shading of the leaves also decreased reflexion. Data by Billings & Morris (1951) were used to compute total reflexion coefficients for different types of vegetation, including two desert species, and to explain why these do not normally differ as much as the coefficients for the visible component.

1.6. MONTEITH, J. L. & SZEICZ, G. (1960). The performance of a Gunn–Bellani radiation integrator. *Quart. J. R. met. Soc.* **86**, 91–94.

An alcohol-filled Gunn–Bellani radiation integrator, exposed at Rothamsted from June till December, 1958, gave weekly distillation totals that were a linear function of short-wave radiation on a horizontal surface above a limit of 500 cal./cm.^{2}/week. Laboratory experiments with both alcohol- and water-filled models reveal a threshold radiation intensity which can be estimated from the properties of the distilling fluid and the partial pressure of air within the instruments. Distillation is negligible below the threshold, but above it is proportional to the excess radiation. Because the relation between absorbed heat and radiation incident on a horizontal surface depends on solar altitude and on the proportions of direct and diffuse radiation, it is difficult to predict field response from laboratory data.

1.7. MONTEITH, J. L. & SZEICZ, G. (1960). The carbon dioxide flux over a field of sugar beet. *Quart. J. R. met. Soc.* **86**, 205–214.

The difference in CO_2 concentration at two heights above a sugar-beet crop was measured with a sensitive infra-red gas analyser. The ratio of evaporation to humidity gradient and of total heat flux to wet-bulb temperature gradient gave a transport number for calculating CO_2 flux, assumed proportional to CO_2 gradient and wind speed. In August and September 1958 there was often a constant upward flux at night (mean 0·05 mg.cm.$^{-2}$hr.$^{-1}$) attributed to respiration by plants and soil micro-organisms; but during daylight, photosynthesis gave a downward flux varying with solar radiation and reaching a maximum of 0·4 mg.cm.$^{-2}$hr.$^{-1}$. From 31 July to 11 September

the net downward flux of atmospheric CO_2 was 158 ± 29 mg./cm.² compared with an uptake of 217 ± 38 mg./cm.² estimated from dry matter increase of sampled plants. During October there was a net upward flux of 4·9 mg. cm.$^{-2}$day^{-1} attributed to a striking increase in amount of CO_2 produced in the soil.

1.8. PENMAN, H. L. & LONG, I. F. (1960). Weather in wheat—an essay in micrometeorology. *Quart. J. R. met. Soc.* **86**, 16–50.

Data for three summers (1955–57) are presented, obtained from continuous recorders responding to temperature, humidity and wind in and above the wheat crop at levels up to about 2 m. *Section 1* describes the instruments (see Long, *Quart. J. R. met. Soc.* **83**, 202, for details) and *Section 2* the site, 70 × 70 m., which may have been too small for full development of profiles. *Section 3* (from 1955) shows that planting density affects the daily cycles of temperature and humidity in the crop, a thin crop having a lower average relative humidity and a shorter period of saturation on a dew night. Such a night is characterised by a humidity lapse between ground and canopy, and a humidity inversion above the canopy. On the exceptional occasion illustrated both the up flux and the down flux may have reached a maximum rate of about 3 mg./cm.² ground/hour. An adventitious air temperature ripple during a calm night is exploited to derive rough estimates of transport constant in a dense crop: near the ground it approached the molecular thermal diffusivity for air. *Section 4* (from 1956) displays anomalies in temperature and humidity profiles that can arise from interpolating readings within the 400-second cycle of the recorders. It also gives soil temperatures, from which soil thermal diffusivity and soil heat flux are estimated, indicating that on the first sunny June day after rain net heat flux into the ground may be about 30 cal./cm.²—the equivalent of ½ mm. of evaporation. Further rough estimates of heat transport constant within the crop are of order 2–20 cm.²/sec., depending on height and external wind speed. The anomalies in profiles are attributed partly to periodicities in the air parameters almost identical with that of the recording instruments, and partly (*Section 5*, from 1957) to long-persisting differences in temperature and humidity at constant level across the site. Within the crop an average temperature difference of 0·8° C. may persist for four hours at positions 8 m. apart (and a vapour difference of 1·0 mb.), and these "hot" and "damp" spots—not always coincident—move slowly during the day. The differences are smaller above the crop where mixing is more thorough.

Section 6, introducing an analytical Part II which uses the data from a period of 8 days (12–19 June 1957) of fine weather after rain, discusses the generalised profile equation

$$u = \frac{u_*}{k\alpha}\left\{\left(\frac{z-d}{z_0}\right)^{\alpha} - 1\right\}$$

(reducing to the standard logarithmic profile when $\alpha = 0$): measurements of temperature and humidity are not accurate enough to determine α for their profiles, and the swaying of the crop necessitates use of long-period averages of wind speed before α can be determined for wind profiles. Working on 4-hour periods (00–04, 04–08 and so on) (*Section 7*), profiles above the crop can be fitted either with $\alpha = 0$, or a value of α chosen from the Deacon curve of $1 - \alpha$ against Richardson number. Values for a crop height of about 60 cm., with heat transfer (Q_s) and evaporation (E) rates from later sections, are:

Period		0–4	4–8	8–12	12–16	16–20	20–24
Ri		0·080	−0·007	−0·017	−0·010	0·014	0·046
Chosen α		0·20	−0·03	−0·05	−0·04	0·03	0·10
u_*/k	cm./sec.	17	75	158	181	127	66
u_*/k for $\alpha = 0$	cm./sec.	59	67	132	158	130	92
z_0 for $\alpha = 0$	cm.	5	5	11	14	12	12
d for $\alpha = 0$	cm.	38	37	22	14	18	25
Q_s (calc.)	cal./cm.²/4 hr.	−15	+4	+32	+14	−26	−33
E_A (calc.)	cal./cm.²/4 hr.	−0·2	10	82	106	49	14
E_B (measured)	cal./cm.²/4 hr.	−0·2	24	96	107	57	5

The discrepancy in u_*/k during the first period corresponds to a 12-fold difference in estimated shearing stress.

Wind profiles in the crop differ completely in shape during calm and windy weather, in the sense that near the ground the absolute wind speed tends to be constant: the crop behaves as though self-sealing.

Temperature and humidity profiles (*Section 8*) plotted in the form of wind speed against T or e at the same height are, statistically, straight lines above crop level, and in *Section 9* these straight lines are used to determine sensible heat and latent heat transfers (using $\alpha = 0$) for the 48 4-hour periods in the 8 days. The daily totals, and the mean diurnal cycle of evaporation, agree well with direct measures taken simultaneously. Evaporation at night is negligible (see table above). The daily cycle of temperature and humidity (*Section 10*), considered in a little more detail during transitions to inversion or lapse, on a " normal " day and on a day of anticyclonic subsidence, indicates that very dry air does not increase evaporation rates the local energy balance still dominates. The crop seems to meet the threat of severe desiccation by closing its stomata, and a speculative *Section 11* attempts to calculate rates of transfer from the leaves into the ambient air, at various levels in the crop, in terms of leaf morphology, leaf temperature and a ventilation factor. Applied to two periods, one calm with wet surface soil, the other windy with dry surface soil, about half of the water evaporated on the first occasion apparently came from the soil, and none on the second. The total fluxes so estimated agree well with aerodynamic estimates based on wind and humidity profiles over the crop. Derived estimates of transport constant well down in the crop show near identity in calm and in windy periods (cf. wind-velocity measurements, *Section 7*), and at the crop surface they agree well with aerodynamic estimates. *Section 12* discusses some biological and physical implications of the results.

Chemistry Department

Books

2.1. Cooke, G. W. (1960). *Fertilizers and profitable farming.* London: Crosby Lockwood.

2.2. Cooke, G. W. (1958). Contributor to: *Efficient use of fertilizers.* Ed. by V. Ignatieff and H. J. Page. Rome: Food and Agriculture Organisation of the United Nations.

Reviews and General Papers

2.3. Cooke, G. W. (1959). Fertilizers, crop production and soil fertility. *J. Fmrs'. Cl., Lond.* **1959** (5).

2.4. Cooke, G. W. (1959). Soils and fertilizers. *J. R. agric. Soc.* **120**, 126–144.

2.5. Cooke, G. W. (1959). Research on use of fertilizers: Britain's experiments. *Good farming quarterly*, **10** (3), 34–43.

2.6. Mattingly, G. E. G. (1958). Crops. *Rep. Progr. appl. Chem.* **43**, 578–585.

Research Papers

2.7. Arambarri, P. & Talibudeen, O. (1959). Factors influencing the isotopically exchangeable phosphate in soils. Part I. The effect of low concentrations of organic anions. *Plant & Soil*, **11**, 343–354.

The labile phosphate in a non-calcareous and a slightly calcareous soil was determined by isotopic exchange in the presence and absence of 0·001M solutions of a chelating and a non-chelating organic anion. The rate of isotopic exchange curves were analysed graphically to subdivide the labile phosphate into 3 or 4 fractions. The half-lives of exchange for the " rapid ", " medium " and " slow " fractions were between 0·3 to 1·6 hours, 1·8 to 8·6

hours and 25·8 to 46·1 hours, respectively. An "instantaneously-exchanging" component was also sometimes observed.

In the presence of the citrate ion, the total labile phosphate was increased in the non-calcareous soil and decreased in the calcareous soil, whereas the diethyl barbiturate ion (DEB) anions decreased the total labile phosphate in both soils. In general, the citrate ion increased the "rapid" and the "medium" fractions, whereas the DEB anion either did not affect them or decreased them. Again, whereas citrate always increased the phosphate in solution, the effect of DEB anions depended on the soil. The major effect of the organic anions was to decrease the "slowly-exchanging" fraction in both soils.

The half-lives of exchange for the "rapid", "medium" and "slow" fractions were in the order

No organic anion > Citrate > Barbiturate

and the rate constants for a first-order mechanism were in the order

No organic anion < Barbiturate < Citrate

Small but significant differences were observed between the two soils.

2.8. Arambarri, P. & Talibudeen, O. (1959). Factors influencing the isotopically exchangeable phosphate in soils. Part II. The effect of base saturation with sodium and calcium in non-calcareous soils. *Plant & Soil*, **11**, 355–363.

The effect of base saturation of non-calcareous soils with sodium and calcium on their total labile phosphate was studied in solutions of sodium and calcium chlorides of the same ionic strength ($\mu = 0{\cdot}02$). The total labile phosphate in 6 out of 7 soils was between 8 to 40% higher in sodium-saturated soils than in calcium-saturated soils. Much more of the total labile phosphate was in solution in the sodium-saturated soils. The ratio of phosphate in solution in these soils to that in calcium-saturated soils varied from 3·4 to 8·1, with a mean value of about 5·5, as compared with a theoretical value of 4·1. A method is suggested for obtaining "corrected" values for the abnormally high phosphate concentrations in solution from sodium-saturated soils. "Corrected" values give smaller differences between the total labile phosphate in sodium and calcium forms of these soils.

Rates of isotopic exchange of the more slowly exchanging forms of soil phosphate were measured at 25° and 35° C for the sodium- and calcium-saturated forms of one Rothamsted soil. At 25° C rates were four times higher in the sodium-saturated soil than in the calcium-saturated soil, although the total labile phosphate in the two forms was the same. Increasing the temperature to 35° C doubled the rate of exchange in the sodium-saturated soil but had no effect on the calcium-saturated soil. This suggests that the cation-exchangeable calcium is strongly linked to the slowly-exchanging forms of phosphate in the soil.

The rates of isotopic exchange of phosphate in this soil did not change after calcium saturation with either 0·01*M* or 1·0*M* calcium chloride, so precipitation of calcium phosphates during the calcium-saturation procedure is not responsible for the differences between sodium- and calcium-saturated samples.

2.9. Arambarri, P. & Talibudeen, O. (1959). Factors influencing the isotopically exchangeable phosphate in soils. Part III. The effect of temperature in some calcareous soils. *Plant & Soil*, **11**, 364–376.

The influence of temperature in the range 25°–45° C. on the rate of dissolution and the equilibrium concentration of phosphate, on the labile phosphate and its components, and on the rates of isotopic exchange in four soils with varying $CaCO_3$ contents and phosphate status, was investigated. The equilibrium phosphate concentration and the rate of exchange of the slowly labile phosphate of soils of low P status increased abnormally between 35° and 45°. The slowly exchanging component normally constitutes the greater part of the labile phosphate of the soil. Soils of higher phosphate status, irrespective of their $CaCO_3$ content, did not show this abnormal behaviour. The observed difference is connected with the nature and the composition of the basic calcium phosphates associated with the soil calcium carbonate.

2.10. Benzian, B. (1959). Nutrition problems in forest nurseries. *J. Sci. Fd Agric.* **10**, 637–644.

Results from many experiments with Sitka spruce to analyse problems of soil fertility and plant nutrition in forest nurseries show that commercial fertilisers (such as " Nitro-Chalk ", ammonium sulphate, superphosphate and potassium chloride) can safely be used in seedbeds and transplant beds.

Effects in short-term experiments with composts and uncomposted organic manures, with and without additional fertiliser, were related to the major plant nutrients present. Interim results for two long-term rotation experiments, which compare continuous conifer cropping with conifer cropping interrupted by fallow or green crops, showed no benefit from the green crops. Seedlings grown with fertiliser were slightly taller than those grown with compost on average of 8 seasons.

Needle tip-burn in a heathland nursery on a highly leached acid sandy soil was recognised to be caused by copper deficiency and was cured with a foliar application of Bordeaux mixture.

In some older nurseries, often with soil of neutral or near neutral reaction, Sitka spruce and some other conifers remain stunted even with ample manuring. Although the cause is not understood, good growth was obtained after soil acidification, after steaming and after applying formalin or chloropicrin.

This work, which was started in 1945, was done in co-operation with members of the Research Branch of the Forestry Commission.

2.11. Bremner, J. M. (1959). Determination of fixed ammonium in soil. *J. agric. Sci.* **52**, 147–160.

A method of determining fixed ammonium in soil based on estimation of the difference in the amounts of ammonium released on treatment with *N*-HF : *N*-HCl and with *N*-KCl was investigated and compared with the hydrofluoric acid method of Rodrigues and the alkaline distillation method of Barshad.

Results obtained by the *N*-HF : *N*-HCl procedure with profile samples of various soils indicated that 3–8% (average 5·6%) of the nitrogen in the surface soils and 9–44% (average 21·5%) of the nitrogen in the subsoils examined was in the form of fixed ammonium. Rodrigues's method gave much higher values, and Barshad's method gave much lower values.

The proportion of soil nitrogen released by acid hydrolysis as total-N and α-amino-N decreased with depth in the soil profiles, whereas the proportion liberated as ammonium by acid hydrolysis increased with depth. Much of the ammonium released by acid hydrolysis was derived from fixed ammonium in clay minerals.

The proportion of soil nitrogen dissolved by *N*-HF : *N*-HCl increased with depth in the profile, whereas the proportion dissolved by neutral and alkaline reagents used to extract soil organic matter decreased with depth. On average, 23·2% of the nitrogen in the surface soils and 47·4% of the nitrogen in the subsoils was dissolved by a single treatment with *N*-HF : *N*-HCl at room temperature for 24 hours.

2.12. Bremner, J. M. & Harada, T. (1959). Release of ammonium and organic matter from soil by hydrofluoric acid and effect of hydrofluoric acid treatment on extraction of soil organic matter by neutral and alkaline reagents. *J. agric. Sci.* **52**, 137–146.

Treating soil with hydrofluoric acid had little effect on the extraction of organic matter by alkaline or neutral reagents, but it released much ammonium and organic matter. More than 90% of the nitrogen in Rothamsted soils was dissolved by repeated treatments with dilute solutions of hydrofluoric acid and sodium hydroxide.

Treating clay minerals with *N*-HF : *N*-HCl solution at room temperature for 24 hours quantitatively released fixed ammonium from clay minerals; similar treatment of soil is unlikely to decompose organic nitrogen compounds to ammonium. This treatment may provide a method for determining fixed ammonium in soil. Results obtained by it indicated that 4–8% of the nitrogen in surface soils and 19–45% of the nitrogen in subsoils examined was in the form of fixed ammonium.

Some mineral soils contain a significant quantity of ammonium and organic

matter intimately associated with clay minerals; this is not dissolved by neutral and alkaline reagents used to extract soil organic matter but is released by hydrofluoric acid.

2.13. CHAKRAVARTI, S. (1959). Phosphate equilibria in acid soils and phosphated clays with special reference to the role of iron and aluminium. Thesis accepted for Ph.D. Degree of London University.

2.14. COOKE, G. W. & WIDDOWSON, F. V. (1959). Field experiments on phosphate fertilisers, a joint investigation. *J. agric. Sci.* **53**, 46–63.

About 90 field experiments were done over 3 years to test dicalcium phosphate, nitrophosphate, ammoniated fertiliser and Gafsa rock phosphate. All comparisons were made in terms of fertilisers supplying the same total amounts of phosphorus.

Dicalcium phosphate dihydrate was approximately equal to superphosphate for potatoes, grass, kale and barley. In one group of swede experiments, mostly in the North-East of England, dicalcium phosphate was inferior to superphosphate, but it was equal to superphosphate in swede experiments on acid soils in wetter areas.

A nitrophosphate made in England on pilot-plant scale was consistently inferior to superphosphate for barley, potatoes and swedes.

A lightly-ammoniated powdered superphosphate was tested in 1 year, and a more heavily ammoniated granulated NPK mixture based on triple superphosphate was tested in 2 years. The phosphorus in both ammoniated fertilisers behaved similarly and was equal to phosphorus in superphosphate for barley and potatoes; for swedes grown on acid soils the ammoniated products were only two-thirds as efficient as superphosphate.

Gafsa rock phosphate used on acid soils gave yields of swedes and kale similar to those given by two-thirds as much phosphorus applied as superphosphate. Rock phosphate had little effect on the yield of grass cut 3 months after the fertiliser was applied even on acid soils; superphosphate applied at the same time increased yields. A few grass experiments on acid soils were continued to measure residual effects, and Gafsa phosphate became as effective as superphosphate. Gafsa had little immediate or residual effect on grass grown on neutral soils. Gafsa phosphate ground to pass a 300-mesh sieve gave the same yields of swedes, kale and grass as coarser materials of which 50–80% passed the 100-mesh sieve. Generally there was no justification for grinding rock phosphate more finely than is customary, but a few experiments showed significant gains from fine grinding.

2.15. COOKE, G. W. & WARREN, R. G. (1959). Manuring experiments on flax. *Emp. J. exp. Agric.* **27**, 171–186.

In 50 experiments on flax done in 1940–45 to test the effects of manuring on yield and quality of the crop, yields of total produce and deseeded straw were measured precisely, but processing introduced irregularities, and yields for scutched flax were less accurate.

Nitrogen increased average yield of total crop by about 5% and yield of green-scutched flax by about 2%. Phosphate increased both total yield and yield of processed flax by less than 2%. Potash increased average yields of total crop by only 1·5% and of green-scutched flax by 4%. The effects of fertilisers on yield of processed flax depended on the method of processing: nitrogen increased the yield of retted-scutched flax by about 7%, and potash by about 2%; phosphate had only a small effect.

Agricultural salt lowered yields of total crop, of green-scutched flax and the average percentage of scutched flax recovered from the straw.

The average increase in yield from ammonium sulphate was about half as much after grass as after 3 or more years' arable crops. Soils with more than 0·3% total N gave one-third the response to fertiliser nitrogen of soils containing less nitrogen. Measurements of citric-acid-soluble phosphorus and acetic-acid-soluble potassium identified soils where phosphate and potash fertilisers gave profitable responses.

Manuring of flax is justified only when chemical analysis or experience shows that the soil is deficient in one or more of the major plant nutrients.

2.16. GASSER, J. K. R. (1959). Soil nitrogen. IV. Transformations and movement of fertiliser nitrogen in a light soil. *J. Sci. Fd Agric.* **10**, 192–197.

Concentrations of NH_4^+-N and NO_3^--N in the surface (0–6 inches) layer of a light soil, with and without added nitrogen fertiliser, were measured from May to October 1957 on plots free from vegetation and cropped with ryegrass.

Nitrogen fertilisers applied to the soil increased the concentration of mineral nitrogen in the surface layer. On bare land the level of mineral nitrogen in the surface soil remained high until July, when it was decreased by heavy and prolonged rain. NH_4^+-N from ammonium sulphate or urea was converted to NO_3^--N slowly; 20 weeks were required to nitrify all the added nitrogen.

When established, ryegrass removed nitrate very rapidly from the soil and brought the level of NO_3^--N to <1 p.p.m. both on plots with and without fertiliser-N. On plots dressed with ammonium sulphate NH_4^+-N was lost under ryegrass, with no corresponding increase in NO_3^--N. The first cut of grass in July contained three-quarters and the second only one-tenth of the nitrogen applied as fertiliser.

Soil samples taken in October from depths up to 3 feet showed that mineral nitrogen did not accumulate under ryegrass and that nitrate moved downward in uncropped soil.

2.17. (MCDONNELL, P. M., STEVENSON, F. J.) & BREMNER, J. M. (1959). Release of fixed ammonium from soil by ball milling. *Nature, Lond.* **183**, 1414–1415.

2.18. PLESHKOV, B. P. (& FOWDEN, L.) (1959). Amino-acid composition of the proteins of barley leaves in relation to the mineral nutrition and age of plants. *Nature, Lond.* **183**, 1445–1446.

2.19. SHAW, K. (1959). Determination of organic carbon in soil and plant material. *J. Soil Sci.* **10**, 316–326.

A wet-oxidation technique for determining organic carbon in soil, plant material and aqueous plant extracts is described. The oxidation is done by heating the soil or plant sample with a mixture of potassium dichromate, sulphuric and phosphoric acids for 10–15 minutes, and the carbon dioxide liberated is determined gravimetrically after absorption in soda-lime. With slight modifications, the method was used for determining carbon in plant extracts, and it seems suitable for soil extracts. A method is described for removing carbonates without loss of organic carbon. Heating a wet soil at 105° C. causes considerable loss of organic carbon. Inert carbonaceous material, such as coal or charcoal, is oxidised by this wet-digestion method, which gives erroneously high results for the carbon content of soil organic matter.

The method is at least as accurate as the conventional dry-combustion technique and quicker, requiring only 1 hour. The apparatus is simple, and except for the needle valve can be readily constructed from normal laboratory glassware.

2.20. TAYLOR, A. W. (1958). Some equilibrium solution studies on Rothamsted soils. *Proc. Soil Sci. Soc. Amer.* **22**, 511–513.

Experiments to find the variation in composition of solutions brought into equilibrium with samples of four different soils at widely different electrolyte concentrations are described. The ratio law relationship between the potassium- and calcium-ion concentration ($a_K/\sqrt{a_{Ca}}$ = constant) is strictly obeyed only in soils of low potassium status. Variations in soils which received large dressings of potassium are attributed to an exchange reaction by which the amount of readily exchangeable potassium increases as the electrolyte concentration is raised.

2.21. WARREN, R. G. & BENZIAN, B. (1959). High levels of phosphorus and die-back in yellow lupins. *Nature, Lond.* **184**, 1588.

In a Forestry Commission Research Nursery on very acid heathland soil near Wareham, Dorset, yellow lupins (*Lupinus luteus*) grown with fertiliser

often show disease signs, the older leaves shrivelling and occasionally the whole plants dying. Phosphorus values in severely affected plants reached 2·2% of the dry matter, and pot experiments with the soil confirmed that the trouble was caused by excess of phosphorus.

2.22. WEBSTER, R. & GASSER, J. K. R. (1959). Soil nitrogen. V. Leaching of nitrate from soils in laboratory experiments. *J. Sci. Fd Agric.* **10**, 584–588.

The leaching of nitrate was studied by percolating water through columns of clay loam and sandy loam soils.

The light soil lost nitrate more quickly than the heavy soil. Both heavy and light soils lost nitrate faster initially from a coarse fraction (2–10 mm.) than from the unseparated soil A fine fraction (<2 mm.) of the heavy soil initially lost nitrate most quickly, but ultimately most nitrate was leached from the unseparated soil. When water was added slowly at the top of columns of unseparated soils until the bottom became wet, nitrate moved downwards, but not uniformly; both soils had a minimum in the nitrate concentration near the bottom of the column. It is suggested that drainage water flows initially over the structural units, and only through the mass of soil when it is completely saturated, so that nitrate is first lost from the surface of the structural units and later from the soil mass as a whole.

2.23. WIDDOWSON, F. V. (1959). The effects of nitrogen upon three stiff-strawed winter wheat varieties. *J. agric. Sci.* **53**, 17–24.

Eleven winter wheat experiments done from 1955 to 1957, compared the effects of nitrogen on Heine 7, Hybrid 46 and Minister. In 1955 the experiments tested " Nitro-Chalk " top-dressings at 0·45, 0·90 and 1·35 cwt. N/acre. In addition, drilled dressings supplying 0·15 cwt. N/acre were supplemented with either 0·30 or 0·75 cwt. N/acre as a top-dressing. In the 1956 and 1957 experiments " Nitro-Chalk " top-dressings were applied at 0·60 and 1·20 cwt. N/acre. In addition, divided dressings were compared by supplementing 0·15 cwt. N/acre by combine-drill with 0·45 cwt. N as top-dressing.

Yield was significantly increased by the first increment of nitrogen in 23 of the 33 comparisons. Additional gains from the second increment of nitrogen occurred in only 7 of the comparisons. Responses to nitrogen varied considerably between seasons. Large and consistent responses were obtained at all centres in 1955, and dressings supplying 0·9 cwt. N/acre were well worthwhile. In 1956 responses were generally smaller, and more than 0·6 cwt. N/acre was justified at only 2 centres. Mean responses in 1957 were lower than those in 1955 and 1956, and 0·6 cwt. N/acre gave maximum yields at 3 of the 4 centres.

Dividing dressings of nitrogen between autumn and spring produced no significant differences. On average, yields were higher when the whole of the nitrogen was given in spring than when part was given in autumn by combine-drill.

Hybrid 46, the only variety able to take consistent advantage of the heaviest rates of manuring, each year produced the highest percentage increase in yield, and Minister the lowest. Hybrid 46 also contained the highest percentage of nitrogen in the grain at each level of manuring. Hybrid 46 converted more of the fertiliser nitrogen into grain or crude protein than either of the other varieties.

2.24. WIDDOWSON, F. V., PENNY, A., WILLIAMS, R. J. B. & COOKE, G. W. (1959). The value of calcium nitrate for spring-sown cereals. *J. agric. Sci.* **52**, 200–206.

Seven experiments on spring barley and five on spring wheat in 1955–57 compared ammonium sulphate and calcium nitrate applied to the seedbeds at 0·3 and 0·6 cwt. N/acre. The fertilisers were tested both when broadcast and when drilled with the seed.

Consistently higher yields of barley were produced by drilling than by broadcasting ammonium sulphate. Drilling calcium nitrate at 0·3 cwt. N/acre was superior to broadcasting for barley, but when applied with the seed at 0·6 cwt. N/acre it retarded germination and early growth and yields were

smaller than when it was broadcast. Broadcast dressings of both fertilisers gave higher yields of wheat than combine-drilled dressings.

Calcium nitrate and ammonium sulphate gave similar yields and nitrogen contents of both crops when the fertilisers were broadcast on the seedbed. The low rate of both fertilisers did not affect the percentage of nitrogen in barley grown in 1955 and 1956, whereas the higher rate caused small increases. In 1957 both rates of dressing considerably increased the percentage of nitrogen in grain.

For stiff-strawed varieties of spring barley and spring wheat 0·5–0·6 cwt. N/acre should be applied when sowing; this rate is unlikely to cause serious lodging in eastern England. Ammonium sulphate and calcium nitrate are equally suitable, except that combine-drilling of the nitrate may check germination and decrease yield in dry weather.

2.25. Widdowson, F. V., Penny, A., Williams, R. J. B. & Cooke, G. W. (1959). Comparisons between combine-drilling and broadcasting muriate of potash for spring barley. *J. agric. Sci.* **53**, 10–16.

Twelve experiments in Bedfordshire and Hertfordshire in 1955–57 compared combine-drilling and broadcasting muriate of potash for barley. Ordinary mineral soils were used, one with more than 25% of calcium carbonate.

On average of all the experiments in each year, 0·25 cwt. K_2O/acre drilled with the seed gave higher yields than 0·5 cwt. K_2O/acre broadcast and worked into the seedbed. The average extra yields of barley from combine-drilling, as compared with broadcasting, were 1·2 cwt./acre with 0·25 cwt. K_2O/acre and 2·0 cwt./acre of grain with 0·5 cwt. of K_2O. In 21 of the 24 comparisons drilling gave higher yields than broadcasting, and in 8 the effects were significant. Combine-drilling gave higher average yields of straw than broadcasting.

The low and high rates of combine-drilled muriate of potash increased yields on average by 13% and 16%, respectively. Only a small proportion of the applied potassium was taken up by the crops; apparent recoveries by grain plus straw averaged 11% of the light drilled dressing and 8% of the heavy dressing. The response was not closely related to values for dilute hydrochloric-acid-soluble potassium or exchangeable potassium in the soils.

Pedology Department

General Papers

3.1. Stephen, I. (1959). Recent advances in pedology—Pedogenic weathering. *Sci. Progr.* **47**, 306–313.

3.2. Stephen, I. (1959). Some aspects of soil mineralogy. *Rep. Rothamst. exp. Sta.* for 1958, 205–213.

Research Papers

3.3. Avery, B. W., Stephen, I., Brown, G. & Yaalon, D. H. (1959). The origin and development of brown earths on Clay-with-flints and Coombe deposits. *J. Soil Sci.* **10**, 177–195.

For abstract see 17.1 below.

3.4. Brown, G. & Stephen, I. (1959). Expanding-lattice minerals from Shropshire. *Miner. Mag.* **32**, 251–253.

X-ray and optical data are given for two types of expanding-lattice minerals occurring in weathered rock and soil in Shropshire.

3.5. Gallavan, R. C. (1959). Bulb breaking correction for heats of wetting determinations. *Brit. J. appl. Phys.* **10**, 398.

Some factors affecting the heat generated when an evacuated glass bulb is broken in water at 25° C. were studied using a calorimeter of high sensitivity.

The importance of the gaseous content of the water in the calorimeter is illustrated by deliberate variation of the carbon dioxide content. By careful control of factors discussed, heats of breaking were measured that are reproducible to $\pm$ 0·005*J* of the mean value.

3.6. Greene-Kelly, R. (1959). Birefringence of Montmorillonite Complexes. *Nature, Lond.* **184**, 181.

3.7. (Grossman, R. B.), Stephen, I., (Fehrenbacher, J. B., Beavers, A. H. & Parker, J. M.) (1959). Fragipan soils of Illinois: II. Mineralogy in reference to parent material uniformity of Hosmer silt loam. *Proc. Soil Sci. Soc. Amer.* **23**, 70–73.

The mineralogy of Hosmer silt loam, a bisequal soil with a fragipan, was studied to determine whether there is a lithological discontinuity between the parent material of the upper and lower sequum. Differences observed between the two sequa in respect to the mineralogy of the heavy and light silt-sized fractions may be accounted for by a progressive decrease in the weathering intensity with depth and are not suggestive of a lithological discontinuity in parent material. The clay mineralogy for the B-horizons of the two sequa was similar for the 2·0–0·2-μ and the <0·2-μ fractions taken individually. For the total clay fraction, however, a higher percentage of montmorillonite was in the $B^1{}_2$-horizon of the lower sequum; this may be explained by illuviation.

3.8. (Grossman, R. B.), Stephen, I., (Fehrenbacher, J. B. & Beavers, A. H.) (1959). Fragipan soils of Illinois: III. Micromorphological studies of Hosmer silt loam. *Proc. Soil. Sci. Soc. Amer.* **23**, 73–75.

Micromorphological studies indicate that the B_2-horizon of the upper sequum is at present an apparently stable, non-illuvial horizon, whereas the B-horizons of the lower sequum are illuvial in character, and in the process of degradation to form the encroaching $A^1{}_2$-horizon. An attempt is made to relate resistance to mechanical breakdown of the major horizons to their micromorphology.

3.9. Le Riche, H. H. (1959). Molybdenum in the Lower Lias of England and Wales in relation to the incidence of Teart. *J. Soil Sci.* **10**, 133–136.

An explanation is offered for the fact that the toxic levels of molybdenum occurring in the Lower Lias soils of Somerset do not occur in soils of Glamorgan, apparently derived from the same zones of the Lower Lias. This is attributable to the parent rock being free from the abnormally high levels of molybdenum found in Somerset, which in turn probably results from the Glamorgan Lias having been laid down close to the contemporary coastline.

Soils high in molybdenum are to be expected in the Vale of Marshwood (Dorset), but the topography of this district is such that they probably occur in too small pockets to cause serious trouble.

3.10. Le Riche, H. H. (1959). The distribution of certain trace elements in the Lower Lias of southern England. *Geochim. et cosmochim. Acta*, **16**, 101–122.

The apparent rarity of the conditions which give rise to the teart disease of cattle in central Somerset has led to a study of the distribution of molybdenum in the Lower Lias shales from which the teart soils are derived.

Analyses of many specimens of shale from two boreholes and from outcrops on the coasts of Dorset and Glamorgan showed considerable variation over the formation, but correlations were found between the concentrations of molybdenum, vanadium, copper and nickel. The amounts of these elements in the shales are related to the organic carbon content, and these together are related to the percentage of calcium carbonate, reaching a maximum with 20–50% $CaCO_3$.

Detailed study of one shale specimen showed that, despite the correlation of these elements with organic carbon, they are not all associated with it. Some of the molybdenum is associated with the silicates and pyrite, whereas nearly all the vanadium is in the silicates. Copper and nickel appear to be mainly organically bound, although some of the nickel is in exchangeable form.

Soil Microbiology Department

Books

4.1. Walker, N. (1960). *Soil biology*. An English translation of "Bodenbiologie, mit besonderer Berücksichtigung der Tierwelt", by W. Kühnelt, with revisions and supplementary material by the author. London: Faber & Faber.

General Papers

4.2. Cooper, R. (1959). Bacterial fertilizers in the Soviet Union. *Soils & Fert.* **22**, 327–333.

Research Papers

4.3. Gibson, A. H. (1959). A study of the physiology and cytology of nodule formation on legumes. (*Doctoral Thesis.*)

Small amounts of combined nitrogen (2 p.p.m. or more of NO_3-N—equivalent to 20 μg. N/plant in the medium), delayed nodulation of clover and lucerne in direct relation to the amount of nitrate taken up by the plant (up to about 160 μg. N/seedling). Similar concentrations of NO_3-N were equally inhibitory, whereas NH_4-N and certain organic forms of nitrogen did not inhibit, although they were assimilated at about the same rate as NO_3-N. The inhibitory effect of low concentrations of nitrate and nitrite ions is specific and not related to the carbohydrate–nitrogen balance within the plant. Small amounts of combined nitrogen increased the total number of nodules formed.

"Preplanting" media stimulates initial nodulation, largely because the preplant removes small amounts of contaminating nitrate nitrogen in the water, but in N-free medium substances secreted by the preplant also sometimes affect nodule formation slightly.

4.4. Nutman, P. S. (1959). Some observations on root hair infection by nodule bacteria. *J. exp. Bot.* **10**, 250–263.

The infection by nodule bacteria of the root hairs of *Vicia hirsuta* and of 12 species of *Trifolium* is described. The proportion of root hairs deformed by bacterial secretions varies between host species and from point to point along the root, but is unaffected by bacterial strain. Infection is more frequent in regions of maximum curling. Infection threads differ in their place of origin in the hair (apical or lateral), their mode of development and detailed morphology; some of these differences are characteristic of host species. Infection threads often abort in the root hair; abortion was least with 2-week-old seedlings infected at about 12 sites. The proportion of lateral infections increases with seedling age.

Root-hair curling, infection thread initiation and growth are associated with the near presence of the host-cell nucleus. The observations support the hypothesis that the infection thread forms by invagination of the root-hair wall.

No infections were observed in the root hairs of nodulated plants of *Lotus hispida, Lotus augustissimus* and *Anthyllis vulneraria*.

4.5. Parle, J. N. (1959). The influence of the soil fauna on the soil microorganisms. (*Doctoral Thesis.*)

The microflora of the gut of *Allolobophora caliginosa, Allolobophora longa* and *Lambricus terrestris*, and of the casts of *A. longa* were studied. The numbers of actinomycetes and bacteria present in material ingested by worms increased greatly during its passage through the gut, which usually took 24

hours. No changes were noted in the numbers of yeasts or fungi. Cellulase and chitinase were produced by the earthworm and not by the intestinal flora. The numbers of yeasts and fungi increased rapidly when casts aged, but actinomycetes or bacterial numbers did not change consistently. The stability of soil aggregates increased logarithmically as casts aged, and this was correlated with the increase in the length of fungal hyphae. Casts contained more polysaccharide than the soil. Total and mineral nitrogen levels in fresh casts were high; inorganic nitrogen was mainly as NH_3-N, which nitrifying organisms rapidly converted to nitrate.

4.6. Skinner, F. A. (1960). The isolation of anaerobic cellulose-decomposing bacteria from soil. *J. gen. Microbiol.* **22**, 539–554.

A strictly anaerobic mesophilic species of cellulose-decomposing bacteria was isolated from soil by a new technique. Liquid and solid media containing finely-divided cellulose were used, and flocculation of the cellulose particles in agar medium was prevented by incorporating a little sodium carboxymethylcellulose. Cellulolytic colonies in cellulose agar medium were of two types, punctiform and spreading. The isolate, derived from a punctiform colony, digested cellulose, forming formic, acetic and malic acids, carbon dioxide and hydrogen. Surface colonies on yeast peptone cellulose agar were differentiated into convex central zones and thin, irregular margins. In deep culture with the same agar medium, the isolate either grew as discrete lenticular colonies or spread rapidly throughout the medium. Neither form was stable enough to isolate from the other, but spreading growth was partly suppressed by growing the isolate in yeast peptone cellobiose agar containing lithium chloride. The isolate is probably a strain of *Clostridium cellobioparum* Hungate, but differs from it in producing little or no cellobiose but abundant glucose from cellulose in liquid culture.

Botany Department

General Papers

5.1. Thurston, J. M. (1960). Dormancy in weed seeds. *In*: The biology of weeds. A symposium of the British Ecological Society, ed. J. L. Harper. Oxford: Blackwell Scientific Publications. (In the press.)

5.2. Welbank, P. J. (1960). Toxin production from *Agropyron repens*. *In*: The biology of weeds. A symposium of the British Ecological Society, ed. J. L. Harper. Oxford: Blackwell Scientific Publications. (In the press.)

Research Papers

5.3. Humphries, E. C. & Thurston, J. M. (1959). Bulbil formation in *Sedum telephium*. *Nature, Lond.* **183**, 1343.

Formation of bulbils on a vegetative plant of *Sedum telephium*, in the axils of the upper leaves where flowering stems would normally arise, is described. Bulbil formation has not previously been reported in the genus *Sedum*.

5.4. Humphries, E. C. & Wheeler, A. W. (1960). The effects of kinetin, gibberellic acid and light on expansion and cell division in leaf disks of dwarf bean (*Phaseolus vulgaris*). *J. exp. Bot.*

The effects of kinetin (Kn), gibberellic acid (GA) and light on cell expansion and division in disks from 6-day-old etiolated primary leaves of dwarf bean are described. Cell number was determined by direct counting after disks were digested in a pectinase/EDTA mixture to separate the cells. Kn increased leaf expansion wholly by increasing cell size. GA also increased cell size; it increased cell division in the dark, but not in the light. Light also increased cell size and cell division; it eliminated the effect of GA on cell division, but enhanced its effect on cell expansion.

5.5. Maciejewska-Potapczyk, W. (1959). Influence of kinetin, β-indoleacetic acid and gibberellic acid on nuclease activity of bean (*Phaseolus vulgaris*) hypocotyls. *Nature, Lond.* **184**, 557.

The activities of ribonuclease (RNase) and deoxyribonuclease (DNase) in extracts of bean hypocotyls were increased by addition of kinetin (Kn) alone, and still more in presence of indoleacetic acid (IAA). IAA alone had no effect, but in presence of Kn it increased the activities of both enzymes. Kn was effective in much lower concentrations on RNase than on DNase. Optimum concentrations of Kn and IAA doubled the activity of RNase and trebled that of DNase. Gibberellic acid had no effect on the activity of either enzyme.

5.6. Maciejewska-Potapczyk, W. (1960). Phosphorus compounds, nuclease, and phosphatase activities in healthy and tumorous stem tissues of *Datura stramonium* L. *J. exp. Bot.*

The phosphorus compounds, nuclease and phosphatase activities in healthy and tumorous stem tissues of *Datura* were compared. The very high level of P in the tumours comes from increased amounts of acid-soluble phosphorus, lipid phosphorus, ribonucleic acid phosphorus and deoxyribonucleic acid phosphorus.

The activities of ribonuclease, deoxyribonuclease and glycerophosphatase were all considerably higher in the tumours than in stem tissue.

5.7. Thorne, G. N. (1959). Photosynthesis of lamina and sheath of barley leaves. *Ann. Bot. Lond., N.S.* **23**, 365–370.

Apparent photosynthesis, in mg. CO_2 absorbed per dm.²/hour, of the sheath and enclosed stem of a barley leaf was about 50% of that of the lamina of the same leaf, when the photosynthesising area was measured as one side of the lamina and the outer exposed surface of the sheath. Apparent photosynthesis of a particular lamina or sheath was about 70% of that of the one above on the same stem.

Respiration per dm.², though not per g. dry weight, of sheath with enclosed stem was greater than of lamina in one experiment done with low-intensity illumination, so that true rates of photosynthesis of lamina and sheath were similar.

For growth-analysis studies the size of the photosynthetic system of cereals should be measured as one side of the leaf laminae plus the outer surface of the combined leaf sheaths. In the later stages of growth the surface area of exposed stem and peduncle should also be included.

5.8. Thurston, J. M. (1959). A comparative study of the growth of wild oats (*Avena fatua* L. and *A. ludoviciana* Dur.) and of cultivated cereals with varied nitrogen supply. *Ann. appl. Biol.* **47**, 716–739.

Wild oats (*Avena fatua* and *A. ludoviciana*) grown in pots with different levels of nitrogen supply showed many similarities to spring barley, winter oats and winter wheat. Small differences that could affect competition between wild oats and cereals occurred mainly in the seedlings. Wild-oat seedlings were smaller than seedlings of cultivated cereals in total dry weight, total nitrogen content, leaf area and number of shoots, but had higher net assimilation rates and soon caught up and passed the cultivated cereals. The difference in net assimilation rate did not persist, and in the later stages of growth differences in dry-matter production depended mainly on differences in leaf area. Another important contrast between wild oats and cultivated cereals was that 98–100% of the wild-oat seeds but none of the crop seeds were dormant 2 months after harvest.

Ear emergence in wild oats spread over a longer period, the range of ear heights was greater, and the tallest ears were smaller than in the corresponding cultivated cereals. Assimilation in the ear appeared to account for less of the total dry matter of plants of wild and cultivated oats than of wheat. Wild oats produced more seeds per plant, but the 1,000-grain weight, and hence the total dry weight of seeds, was less than in cultivated cereals.

Increased nitrogen supply had similar effects on the wild oats and cultivated

cereals. Wild oats took up the same amount of nitrogen per plant as winter oats and winter wheat, but more than spring barley.

It is concluded that wild oats are most susceptible in the seedling stage to competition from the crop, and that nitrogenous fertiliser applied to an infested field is unlikely to alter the balance between the yields of crop and of wild oats.

5.9. WATSON, D. J. & WITTS, K. J. (1959). The net assimilation rates of wild and cultivated beets. *Ann. Bot. Lond., N.S.* **23**, 431–439.

The net assimilation rate (E) of Kleinwanzleben sugar beet was the same as that of three types of wild sea-beet (*Beta vulgaris* subsp. *maritima*) when the leaf area index (L) was near to 1. In a subsequent period, when mean L of sugar beet and of the leafiest wild beet type was 2·5, there was an inverse relation between E and L of the three wild types, and E of sugar beet was then much greater than that of the wild type with equal L, but was little different from that of the wild type with smallest L (about 1·5). It is concluded that the development of sugar beet from its wild ancestors by selection and breeding has not affected the intrinsic photosynthetic efficiency of the leaves, but has diminished the effect of mutual interference between leaves, so that E falls less rapidly as L increases, i.e., it has decreased the leaf-density dependence of E. This change may be related to the difference in form between sugar beet and wild beet plants

5.10. WITTS, K. J. (1960). The germination of *Polygonum* species in the field and in the glass-house. *J. Ecol.* **48**, 215–217.

Three species of *Polygonum* germinated equally during 1957, but *P. aviculare* and *P. convolvulus* ceased germinating in May, whereas *P. persicaria* continued until July. The greater abundance of *P. persicaria* in all the soil samples may be explained by its ability to continue germination into the summer after herbicide applied in May of the 2 previous years had destroyed all weed seedlings that had appeared by that date. The percentage germination of each species was greater in the glass-house than in the field, but their times of germination were similar in the two conditions.

Biochemistry Department

General Papers

6.1. HOLDEN, M. (1960). Nucleic acid content of tissues of higher plants. *Biochemists Handbook*. (In the press.)

6.2. PIRIE, N. W. (1959). Edible protein from green leaves. *British Vegetarian*, **1**, 229–232.

6.3. PIRIE, N. W. (1960). Biological replication considered in the general context of scientific illusion. *New Biol.* **31**, 117–135.

6.4. PIRIE, N. W. (1959). Leaf protein as human food. *Lancet*, 28 Nov. 1959, 961–962.

6.5. PIRIE, N. W. (1959). Farmer and biochemist versus engineer and doctor. *Proc. Manchester lit. & phil. Soc.* **101**, 96–111.

6.6. PIRIE, N. W. (1959). Scientific Writing. *Times lit. Suppl.*, 26 Sept.

Research Papers

6.7. BAWDEN, F. C. & PIRIE, N. W. (1959). The infectivity and inactivation of nucleic acid preparations from tobacco mosaic virus. *J. gen. Microbiol.* **21**, 438–456.

The infectivity of nucleic acid preparations made by disrupting tobacco mosaic virus with phenol was increased, relative to that of intact virus, by

keeping test plants in darkness or at 37° for some time before they were inoculated. The differences in susceptibility to infection of leaves in different physiological states was too great to be explained by differences in the ability of leaf extracts to inactivate nucleic acid preparations *in vitro*. The spontaneous inactivation of the preparations *in vitro* was not prevented by inhibitors of ribonucleases, and most additions to the preparations increased the rate of inactivation. Not all the inactivations are readily explicable on the assumption that the minimal infective unit is a pure nucleic acid built up solely from nucleotides. Leaf sap and saliva are reasonably assumed to inactivate because they contain ribonuclease; also, inactivations by formaldehyde, phenylglyoxal and thiaminase in the presence of thiamine may well reflect reactions with known components of nucleic acids. However, it is less easy to invoke such actions to explain the inactivation by spermine, interferon, some oxidising agents, leaf mitochondria in the presence of some other substances and the greater rate of inactivation *in vacuo* than in air. Although nucleic acid seems essential for infectivity, it seems prudent to suspend judgement about the precise chemical identity of the minimal infective unit.

6.8. Festenstein, G. N. (1959). Substrate specificity of rumen cellulolytic enzymes. *Biochem. J.* **72**, 75–79.

Studies on cell-free extracts of enzymes from sheep rumen showed gluconolactone to be a specific inhibitor of glucose production from carboxymethylcellulose, cellulose dextrin and also cellosaccharides from cellobiose to cellopentaose. Inhibition of hydrolysis as measured by reducing sugar estimation is generally less than that in terms of glucose, and it decreases with increasing chain length of substrate.

6.9. Holden, M. (1959). Processing of raw cocoa. III. Enzymic aspects of cocoa fermentation. *J. Sci. Fd Agric.* **10**, 691–700.

The changes in the levels of some oxidising and carbohydrate-splitting enzymes of Amelondado cacao bean cotyledons, during both large- and small-scale fermentations, were determined, on samples of beans taken after various periods of fermentation from the top and centre of heaps of different sizes. Enzymes were inactivated sooner in the top layer, where the temperature rise was more rapid, than at the centre. Enzyme levels started to diminish during the period when the beans were dying and continued until, after 3 days' fermentation, little or no activity remained. The results suggest that prolonging fermentation for several days after the beans are dead is neither necessary nor desirable.

A germination inhibitor found in the pulp and testas of beans decreased in amount during ripening and disappeared during fermentation.

6.10. Morrison, J. E. & Pirie, N. W. (1960). The presentation of leaf protein on the table. *Nutrition*. (In the press.)

The different forms that fresh and dried leaf protein can take, and the problems that each poses in presentation, are discussed. Fifteen different recipes are given; in some the protein is left uncovered and dark green, in others it is encased in a thin batter or pastry coating. The usual starting material for these recipes is the perishable moist protein that is the primary product of the leaf protein extraction process, but a few stable forms of presentation are described.

6.11. Pierpoint, W. S. (1960). Mitochondrial preparations from the leaves of (*Nicotiana tabacum*). 2. Oxidative phosphorylation. *Biochem. J.*

The oxidation of organic acids, catalysed by a sedimentable preparation from tobacco leaves, is accompanied by a disappearance of orthophosphate. Adenosine polyphosphates, hexokinase and glucose stimulate this disappearance, whereas 2 : 4-dinitrophenol inhibits it. The ratio of phosphate disappearing to oxygen absorbed (P : O ratio) depends on the substrate, and varies between 1 and 2. Nucleotide phosphates and glucose 6-phosphate accumulate during the course of the reaction. The nucleotide phosphates become radioactive when ^{32}P orthophosphate is present. The oxidation of

organic acids catalysed by these tobacco preparations is accompanied by an evolution of CO_2. Respiratory quotients vary with the substrate from 0·28 for succinate to 1·5 for citrate.

6.12. PIERPOINT, W. S. (1960). Mitochondrial preparations from the leaves of (*Nicotiana tabacum*). 3. Glycollic oxidase and fumarase activity. *Biochem. J.*

Fractions of extracts from tobacco leaves that sediment between 1,000 and 10,000 *g* oxidise glycollate by a mechanism which does not involve cytochromes, but probably does involve glycollic oxidase. These preparations, however, contain only a small proportion (8%) of the total glycollic oxidase of these extracts; the bulk of it is in the supernatant fraction, from which it is not sedimented by centrifugation at 55,000 g. In contrast, nearly all the fumarase of the extracts is concentrated in the sedimentable fraction, although it is liberated by disruptive treatments. The fumarase, an -SH dependent enzyme, is enough to account for its expected rôle in the fumarate oxidation of these preparations, and seems unlikely to be a rate-limiting step.

Plant Pathology Department

General Papers

7.1. BAWDEN, F. C. (1957). Gradations and transitions between pathogenicity and commensalism in infections with plant viruses. *In*: Symposium on " Latency and masking in viral and rickettsial infections ", Wisconsin. (Burgess Publishing Co.)

7.2. BAWDEN, F. C. (1959). Evolution and viruses. *In*: Symposium on Evolution, Duquesne University, Pittsburgh, Pa.

7.3. BAWDEN, F. C. (1959). Viruses: retrospect and prospect. (The Leeuwenhoek Lecture.) *Proc. Roy. Soc. B.* **943**, **151**, 157–168.

7.4. BUXTON, E. W. (1959). Factors affecting pathogenic *Fusarium oxysporum* in the rhizosphere of peas. *IXth Int. Bot. Congr., Montreal, Abstracts*: 54–55.

7.5. BUXTON, E. W. (DOLING, D. A. & REYNOLDS, J. D.). (1959). Getting the better of the pea wilt. *Fmrs Weekly*, **50**, 88–89.

7.6. HARRISON, B. D. (1959). Soil-borne virus diseases of plants. *IX Int. Bot. Congr., Montreal, Abstracts*: p. 152.

7.7. KASSANIS, B. & (POSNETTE, A. F.) (1959). Thermotherapy of virus-infected plants. *IX Intern. Bot. Congress, Montreal, Abstracts*: p. 186.

7.8. KLECZKOWSKI, A. (1959). Effects of non-ionising radiations on plant viruses. *Proc. New York Acad. Sci.* (In the press.)

Research Papers

7.9. BANKS, C. J. & NIXON, H. L. (1959). The feeding and excretion rates of *Aphis fabae* Scop. on *Vicia faba* L. *Ent. exp. & appl.* **2**, 77–81.

(For summary see No. 10.5 below.)

7.10. BAWDEN, F. C. (1959). Effect of nitrous acid on tobacco mosaic virus: mutation or selection? *Nature, Lond.* **184**, B.A.27–B.A.29.

The conclusion that nitrous acid causes mutations in tobacco mosaic virus is questioned, because the phenomenon of the number of necrotic local lesions

produced in Java tobacco increasing while the total infectivity of preparations decreases can be duplicated by inoculating plants with mixtures containing tomato aucuba mosaic and tobacco mosaic virus in different proportions.

7.11. Bawden, F. C. & Kleczkowski, A. (1959). Photoreactivation of nucleic acid from tobacco mosaic virus. *Nature, Lond.* **183**, 503–504.

The free nucleic acid of tobacco mosaic virus is not only more susceptible than the intact virus to inactivation by ultraviolet radiation but also undergoes photoreactivable changes which it is protected against when combined with the virus protein.

7.12. Bawden, F. C. & Pirie, N. W. (1959). The infectivity and inactivation of nucleic acid preparations from tobacco mosaic virus. *J. gen. Microbiol.* **21**, 438–456.

(For summary see No. 6.7 above.)

7.13. Buxton, E. W. (1959). The occurrence of *Fusarium* wilt of melon in Britain. *Plant Path.* **8**, 96–97.

From wilted melon plants (*Cucumis melo*, L.), at Chorleywood, Herts, in 1956 and 1957, pathogenic isolates of *Fusarium oxysporum* Fr. f. *melonis* (Leach and Curr.) Snyd. and Hans. were consistently isolated. The fungus wilted four melon varieties, but had no effect on cucumber or vegetable marrow.

7.14. Buxton, E. W. (1959). Production of perfect stage in a nutritionally deficient mutant of pathogenic *Fusarium oxysporum* after ultraviolet irradiation. *Nature, Lond.* **184**, 1258.

Among several isolates of *Fusarium oxysporum* f. *pisi* used for genetical work, one which had mutant nutritional requirements developed small red perithecia. These did not provide asci for over 2 years, but recently asci and ascospores have appeared in the now abundant perithecia. Identified as *Nectria haematococca* Berk. & Br., the cultures yield perithecia from single ascospores or from single spores of the *Fusarium* stage. Crosses were made with other *formae speciales* of *Fusarium oxysporum*, in the hope of extending work on the genetics of pathogenicity. It may also be possible to check cytological details of the parasexual cycle in *Fusarium*, and to investigate taxonomic relationships between *F. oxysporum* and other species of Fusaria that have *Nectria* perfect stages.

7.15. Buxton, E. W. & Perry, D. A. (1959). Pathogenic interactions between *Fusarium oxysporum* and *Fusarium solani* on peas. *Trans. Brit. mycol. Soc.* **42**, 378–387.

The previous observation that the severity of wilt caused by *Fusarium oxysporum* f. *pisi* on pea variety Onward was decreased by simultaneous inoculation with the pea foot-rot pathogen, *F. solani* f. *pisi*, was confirmed by inoculation tests in a glasshouse; the decrease was statistically significant and was increased by increasing the amount of *F. solani* in the inoculum. Inoculating plants with *F. solani* before *F. oxysporum* gave less wilt than inoculating plants with both fungi simultaneously. The decrease of wilt occurred in sterilised soil, showing that other soil micro-organisms are not involved in the phenomenon.

Field observations on a wilt-susceptible pea variety growing in infested soil showed that although *F. solani* entered pea roots earlier than did *F. oxysporum*, the plants were killed by the wilt pathogen. Wilt spread less rapidly along rows of peas from foci of inocula containing both *F. solani* and *F. oxysporum* than from foci of *F. oxysporum* alone. Foot-rot also spread less from a mixed inoculum than from *F. solani* alone.

Differences in the appearance of the macrospores of the two fungi were considered to be the only reliable taxonomic criteria for distinguishing the two species.

7.16. (CADMAN, C. H.) & HARRISON, B. D. (1959). Studies on the properties of soil-borne viruses of the tobacco-rattle type occurring in Scotland. *Ann. appl. Biol.* **47**, 542–556.

Soil-borne viruses of the tobacco-rattle type occur in sandy and peaty soils in many parts of Scotland, and infect many species of crop and weed plants, often only in the roots. They also occur in potato plants that have diseases of the stem-mottle type. The viruses can be distinguished from other soil-borne viruses occurring in Britain by the symptoms they cause in tobacco, *Chenopodium amaranticolor* and French bean.

Some virus cultures (M types) multiplied readily and were easily transmitted by mechanical inoculation, whereas others (NM types) were transmitted mechanically only with difficulty. The behaviour of NM types remained constant during 20 successive subcultures. Only slight differences were noted between the symptoms caused by M and by NM types. A proportion of the single-lesion isolates made from cultures of the M type behaved in every way like NM types: this proportion differed with different parent cultures. Single-lesion isolates that were of the M type mostly caused somewhat different symptoms from their parent culture. All M types that were tested, including one from the Netherlands, were serologically related: however, different cultures, and different samples of the same culture propagated on different occasions, varied in antigenic constitution. Belladonna mosaic virus, described by Smith (1943) from England, was serologically related to tobacco-rattle virus. Infection with each of several M types (including the Dutch culture), protected *Nicotiana sylvestris* plants from the effects of each of the others. NM types also protected *N. sylvestris* from the effects of the Dutch culture, but the latter was subsequently isolated from the tip leaves of such plants. Sap from plants infected with cultures of the M type contained characteristic rod-shaped particles, but none was seen in sap from plants infected with NM types.

In tobacco sap M types had the following properties: thermal inactivation point, 80°–85° C.; dilution end-point, 10^{-5}–10^{-6}; longevity *in vitro*, over 6 weeks; infectivity survived freezing and precipitation by ammonium sulphate, but not exposure to pH 3. In many of its properties, including the unusual one of failing to show photo-reactivation after ultraviolet irradiation, tobacco-rattle virus resembles tobacco mosaic virus.

Soil-borne viruses occurring in Britain are classified into three groups, exemplified by tobacco necrosis, tomato black ring and tobacco-rattle viruses.

7.17. (CADMAN, C. H.) & HARRISON, B. D. (1960). Studies on the behaviour in soils of tomato black ring, raspberry ringspot and arabis mosaic viruses. *Virology*, **10**, 1–20.

When turnip, sugar beet or spinach seedlings were grown for varying periods in soils containing tomato black ring (TBRV) and raspberry ringspot viruses, and then transplanted to virus-free soil, some seedlings became infected in 3 days and many in 9 days. The ease with which TBRV infected and multiplied in roots decreased with increasing age of seedling. The presence of the viruses in soils was shown by growing bait seedlings in them but not by inoculating leaves of test plants with soil extracts. In highly infective soils one bait seedling became infected per 100–200 g. soil. Infectivity of soils was abolished by air-drying for a week at 20° C. and was decreased by freezing at −10° C. It was also abolished by treating soils with pentachloronitrobenzene, tetramethyl-thiuram-disulphide, ethylene dibromide and Nemagon, but not by griseofulvin or by mixing the soil with lime or ammonium sulphate. Infectivity of soils containing TBRV was associated with particles that sedimented through 7 cm. water between 30 seconds and 5 minutes, and to a lesser extent with particles sedimenting in 30 seconds.

Pot experiments showed that seedlings grown in non-infective field soil or autoclaved soil did not become infected when watered with highly infective sap. TBRV became established in autoclaved sand when watered with crude eelworm preparations from infective soils, but not when the sand was mixed with washed roots of naturally infected plants. TBRV became established in non-infective field soil when it was cropped with artificially infected sugar beet. The receptivity of this soil to virus seemed specific to the beet ringspot strain of tomato black ring virus and was abolished by autoclaving.

Evidence is adduced that an agent occurring in soil plays a part in transmission of TBRV, and its possible identity among soil-inhabiting organisms is discussed.

7.18. GREGORY, P. H., (GUTHRIE, E. J.) & BUNCE, MAUREEN, E. (1959). Experiments on splash dispersal of fungus spores. *J. gen. Microbiol.* **20**, 328–354.

Splash dispersal (first studied by Faulwetter in 1917) is characteristic of many bacterial plant pathogens and slime-spored fungi. The mechanism of splash was studied in the laboratory under simplified conditions with water drops falling from known heights on to thin films of a suspension of conidia of *Fusarium solani* spread on horizontal glass surfaces. The resulting splash droplets were caught, counted and measured by the naphthol green B slide method (Liddell & Wootten, 1957). Both the total number of droplets produced and of those carrying spores increased as the film thickness decreased, and as the size and velocity of the incident drop increased.

One incident drop 5 mm. in diameter falling on a horizontal film of spore suspension 0·1 mm. thick on a glass surface produced over 5,200 splash droplets, of which over 2,000 carried one or more spores. The sizes of splash droplets ranged from 5 μ to about 2,400 μ, and their size distribution was of the log-probability type. The median diameter was 70 μ for all droplets, and 140 μ for droplets carrying spores. The median horizontal distances travelled by these droplets in still air was 10 and 20 cm. respectively. Increasing the film thickness to 0·5 and 1·0 mm. decreased the total resulting droplets to 3,500 and 2,100 (1,600 and 500 carrying spores), respectively. Neither median diameter nor median distance of horizontal travel were much altered by varying the diameter of incident drop or film thickness. Droplets of diameters between 164 and 655 μ tended to travel farther than either smaller or larger droplets. Small spores, such as those of *Gloeosporium album*, *Colletotrichum lindemuthianum* and *Nectria cinnabarina*, were even more readily picked up from suspension than the macroconidia of *Fusarium solani*.

The number of droplets deposited per unit area on a horizontal plane decreased rapidly with increasing distance from point of impact, and in still air few droplets travelled beyond 70 cm.

Splash on a twig bearing conidial fructifications of *Nectria cinnabarina* produced 2,000 spore-carrying droplets, and the sequence of events is shown by high-speed photography.

A splash droplet consists of an intimate mixture of liquid from both the incident drop and the surface film. The larger splash droplets contain spores when either the incident drop or the surface film is a spore suspension. Raindrops falling at terminal velocity or drops falling more slowly from vegetation can operate the splash dispersal mechanism. Splash in rain or drip from trees may act as a complete dispersal mechanism in still air, or as a "take-off" mechanism leading to dispersal by wind. Both functions are important in plant epidemiology.

7.19. HARRISON, B. D. & (CADMAN, C. H.) (1959). Rôle of a dagger nematode (*Xiphinema* sp.) in outbreaks of plant diseases caused by arabis mosaic virus. *Nature, Lond.* **184**, 1624–1626.

Diseases associated with arabis mosaic virus occurred patchily in raspberry, strawberry and white clover crops in widely separated parts of Britain. Pea seedlings became infected when grown in soil from beneath diseased plants, but soil collected outside the patches of diseased plants was not infective. The distribution in soil of a dagger nematode (*Xiphinema* sp.) was correlated with that of diseased plants. When infective soil was fractionated by sieving, the distribution of infectivity in the fractions roughly paralleled that of *Xiphinema*, and when dagger nematodes were separated from the other material in one such fraction the residue was non-infective. Pea seedlings became infected when infested with hand-picked adult male, adult female or larval *Xiphinema* from soil beneath diseased plants. The infectivity of soil was abolished and *Xiphinema* killed by air-drying the soil at 20° C. for a week or by treating it

with various chemicals. It is concluded that *Xiphinema* is a vector of arabis mosaic virus and that in field conditions the spread of the virus is often limited by the distribution of the nematodes.

7.20. Harrison, B. D. & Nixon, H. L. (1959). Separation and properties of particles of tobacco rattle virus with different lengths. *J. gen. Microbiol.* **21**, 569–581.

Tobacco-rattle virus was isolated from tobacco sap by differential centrifugation: the yield was about 50 mg. virus/l. sap. Purified preparations were highly infective, precipitated optimally at pH 4·0–4·5, and contained one electrophoretic component; chemical analysis and the ultraviolet absorption spectrum suggest they contain about 5% nucleic acid and 95% protein. Most rod-shaped particles in purified preparations are 73–77 mμ or 179–192 mμ long: all are 25 mμ wide. These two components were separated by rate zonal centrifugation in sucrose density-gradients: both have the same density in solution as tobacco mosaic virus, and they have sedimentation constants of about 198s and 295s respectively. No differences were found between long and short particles in serological behaviour, electrophoretic mobility or ultraviolet absorption spectrum; apparently they differ little in gross chemical composition. Only the long particles are infective. Particles slightly shorter than 179 mμ seem non-infective; some of these may be aggregates of two short ones. Short particles rarely aggregate end-to-end at pH 6·8–7·0, but aggregation increases as the pH decreases.

7.21. Harrison, B. D. & Nixon, H. L. (1959). Some properties of infective preparations made by disrupting tobacco rattle virus with phenol. *J. gen. Microbiol.* **21**, 592–599.

Preparations made by treating tobacco rattle virus with phenol are about 5% as infective as the initial virus suspensions when assayed on French bean, but less on tobacco. Virus nucleic acid (NA) seems to be a major constituent of such preparations. By contrast with whole virus, NA preparations lose infectivity when incubated for 20 minutes with 0·02 mg./l. ribonuclease or when stored for a day at 20°. NA preparations contain threads about 1 mμ in diameter, but very few or no virus rods. The infectivity of NA preparations is little affected by high-speed centrifugation for periods in which more than 95% of whole virus is sedimented. Ultraviolet-irradiated NA preparations are photo-reactivable, although irradiated preparations of whole virus are not. NA preparations were only infective when made either from purified virus suspensions or from frozen and clarified saps, which contained infective rod-shaped particles 179–192 mμ long. Phenol treatment of purified non-infective particles 73–77 mμ long yielded non-infective preparations.

7.22. Kassanis, B. Comparison of the early stages of infection by intact and phenol-disrupted tobacco necrosis virus. *Virology*. (In the press.)

Preparations of a tobacco necrosis virus disrupted by phenol were as infective as the parent virus preparation when the two were compared in pH 7 phosphate buffer and about one fifth as infective when compared in water. No virus particles could be detected in the disrupted preparations by electron microscopy, and the preparations were rapidly inactivated by dilute solutions of pancreatic ribonuclease, harmless to the intact virus. At 20° the preparations became inactive in 1–4 days.

Some of the changes detectable in infected bean leaves occur sooner with inoculum of disrupted virus than with intact virus. The infective centres initiated by disrupted virus start to increase their resistance to inactivation by ultraviolet radiation immediately after inoculation, whereas those initiated by intact virus do so only after a lag period of 2–3 hours, and newly formed virus becomes detectable 2–4 hours sooner when the inoculum is disrupted virus. The very first lesions produced by each type of inoculum appear simultaneously, but those produced by disrupted virus reach their final number sooner than those produced by intact virus. The peak rate at which lesions appear is about 4 hours earlier with inoculum of disrupted than with intact virus, and the lesions produced are more uniform in size.

7.23. KASSANIS, B. & TINSLEY, T. W. (1958). The freeing of tobacco tissue cultures from potato virus Y by 2-thiouracil. *Proc. 3rd Conf. Potato Virus Diseases*, Lisse-Wageningen, 1957.

Thiouracil inhibits the multiplication of tobacco mosaic and some other viruses in inoculated leaves, but there is no record of it affecting the amount of virus already present in leaves. Tobacco tissue cultures infected with potato virus Y, however, were freed from the virus by maintaining them for periods of 3 weeks or more on media containing 100 mg./l. of thiouracil. Progenies from these cultures are still free from detectable virus 1 year after the treatment. Spraying thiouracil on growing plants systemically infected with potato virus Y also decreased the virus content of leaves but did not free them from infection. In addition to intrinsic differences between the leaves and tissue cultures, the failure to free infected leaves may be that they contain more than 10 times as much virus as do tissue cultures.

7.24. KLECZKOWSKI, A. (1959). An electrophoretic study of the mechanism of precipitin reactions: variation in reversibility. *Immunology*, **2**, 97–103.

Antibodies to human serum albumin differ from one antiserum to another in the degree of firmness and reversibility of combination with the antigen. These differences are reflected in different behaviours during electrophoresis of soluble antigen–antibody compounds. Molecules of each kind of antibody seem also able to combine with the antigen in more than one way.

7.25. KLECZKOWSKI, A. (1959). Aggregation of the protein of tobacco mosaic virus with and without combination with nucleic acid. *Virology*, **7**, 385–393.

The protein produced by splitting tobacco mosaic virus with alkali has a smaller electrophoretic mobility at pH 7 than the virus, and recombining the protein with the nucleic acid increases its mobility almost to that of the original virus. Nevertheless, the nucleic acid does not seem to contribute appreciably to the surface potential either of the original virus or of the particles of the reconstituted nucleoprotein, because the surface potential of disks and cylinders produced by the protein alone when it is aggregated at pH 7 by exposure to ultraviolet radiation also have a surface potential approaching that of the original virus. This and other evidence suggests that the surface charge density of the protein fragments is non-uniform and that when the fragments form cylindrical aggregates the parts of the surface that are oriented outward are the most negatively charged.

7.26. KLECZKOWSKI, J. & KLECZKOWSKI, A. (1959). Effect of infection with bacteriophage on electrokinetic potential of host bacteria. *J. gen. Microbiol.* **21**, 308–311.

Infection with bacteriophage increased the electrophoretic mobility of pea nodule bacteria (*Rhizobium leguminosarum*) at pH 7. The increase occurred at about the middle of the latent period, suggesting that the bacterial surface alters at this stage of infection.

7.27. MACFARLANE, I. & LAST, F. T. (1960). Some effects of *Plasmodiophora brassicae* Woron. on the growth of the young cabbage plant. *Ann. Bot. Lond.* N.S. (In the press.)

When clubroot galls developed on cabbage inoculated with *Plasmodiophora brassicae* Woron. the distribution of dry matter in the plant was altered. As soon as clubbed roots were visible the stem to root ratio diminished with time until the clubs rotted. After clubs appeared the increase in root weight was nearly all from growth of the clubroot gall, and the rate of growth of tops correspondingly diminished. Succulence of the shoot, water content per unit dry weight, was unaffected.

Increase in total leaf area closely paralleled that of total dry weight. It was slower in diseased plants, and attained a lower limit than in healthy ones. From the 35th day after inoculation onwards diseased plants had fewer and smaller leaves, and their leaves opened more slowly, one new leaf unfolding every 9 days on diseased plants against one every 4 days on healthy plants.

Leaves of diseased plants were both smaller and thinner than those in corresponding positions on healthy plants.

The relationship between the absorbing system, on the one hand, and the assimilating and transpiring system, on the other, was greatly altered; the dry weight of fibrous root per unit leaf area was decreased after infection from 1·20 to 0·79 mg./cm.² 20 days after inoculation and from 1·64 to 0·38 mg./cm.² 82 days after inoculation.

Though infection consistently lowered net assimilation rate, on the average by about 15% of the control value, this decrease was never statistically significant.

Increases in the number of spores in the inoculum progressively decreased the dry weights of tops and fibrous roots, and sometimes increased the dry weight of clubs.

Delaying inoculation increased the initial growth rate of the galls, and sometimes their final size. The extent to which plants were damaged depended more on how long they had been infected than on age at inoculation.

7.28. Nixon, H. L. & Harrison, B. D. (1959). Electron microscopic evidence on the structure of the particles of tobacco rattle virus. *J. gen. Microbiol.* **21**, 582–591.

The structure of tobacco rattle virus (TRV) was studied by examining with the electron microscope: (1) shadowcast mounts of particles partly degraded by treatment with alkali, sodium dodecyl sulphate, or phenol; and (2) unshadowed mounts on thin carbon film of particles treated with solutions of lanthanum nitrate, uranyl acetate, osmium tetroxide, phosphomolybdic acid or phosphotungstic acid.

The particles are tubular, with a central hole of approximately 4 mμ diameter and an outside diameter which varies from 17 to 25 mμ according to treatment. Next to the central hole, which can be filled with lanthanum nitrate or uranyl acetate, is a region 1–1·5 mμ thick, which stains heavily with osmium tetroxide, phosphomolybdic and phosphotungstic acids. The rest of the particle stains lightly with uranyl acetate, phosphomolybdic and phosphotungstic acids, and shows transverse bands 2·5 mμ apart. It is suggested that these bands may represent a helical structure similar to that of tobacco mosaic virus, which TRV resembles in many respects.

7.29. Nixon, H. L. & Woods, R. D. (1959). The structure of tobacco mosaic virus protein. *Virology*, **10**, 157–159.

High-resolution electron microscopy of particles of reaggregated tobacco mosaic virus protein, made by spraying a suspension of the particles in neutral phosphotungstate, gives images which are in remarkably good agreement with the structure of the particles inferred from X-ray-diffraction patterns. The particles are crossed by a regular system of bands spaced 2·5 mμ apart, which are thought to represent the individual turns of the protein helix, and short fragments standing on end show a 16-fold radial symmetry, corresponding to the number of sub-units to be found in a single turn of the helix. Detailed examination of the image of a particle surface often shows small areas in which the arrangement of individual sub-units can be seen.

7.30. Perry, D. (1959). Studies on the mechanism underlying the reduction of pea wilt by *Fusarium solani* f. *pisi*. *Trans. Brit. mycol. Soc.* **42**, 388–396.

The mechanism underlying the decrease caused by *Fusarium solani* f. *pisi* in the severity of pea wilt was studied by examining sites in the soil and in the host where the two fungi might interact.

F. solani produced no substance *in vitro* that inhibited spore germination or growth of *F. oxysporum*, and there was no evidence that the two competed to the detriment of *F. oxysporum* either in the rhizosphere of peas or in the soil. Some water extracts of foot-rot lesions contained a substance inhibitory to the germination of *F. oxysporum* spores, but it could not always be demonstrated. No inhibition was caused by exudates from or in extracts of pea roots infected with *F. solani*.

F. solani colonised the epidermis and outer cortex of pea roots more rapidly and more extensively than did *F. oxysporum*. Three days after inoculation

with *F. solani*, pea roots respired 25% more than uninoculated ones. The physical structure and biochemical nature of the cortex was altered by infection by *F. solani*, so it is concluded that the only part of the infection process of *F. oxysporum* that is changed by the presence of *F. solani* is during passage through the cortex.

7.31. Watson, Marion A. (1958). The specificity of transmission of some non-persistent viruses. *Proc. Xth Int. Congr. Ent.* 1958, 215–219.

When leaves infected with potato virus Y and other non-persistent viruses were exposed to ultraviolet light the infectivity of their expressed saps was reduced, suggesting that the viruses were more concentrated in the epidermis than elsewhere in the leaves.

Non-persistent viruses are transmitted by aphids much more readily after 1 or 2 minutes' feeding on infected leaves than after longer times. With irradiated leaves there was no greater ability after short than after long infection feeding times.

Brevicoryne brassicae (L.) does not transmit cauliflower mosaic virus optimally after 2 minutes infection feeding, and its ability to transmit is not affected by irradiation of the infected leaf on which it feeds. *Myzus persicae* (Sulz.), on the other hand, transmits cauliflower mosaic in the same manner as other non-persistent viruses, and irradiation lowers its ability to transmit after short infection feeds.

Potato virus C is serologically related to potato virus Y, and both are similarly affected by ultraviolet irradiation. But potato virus Y is readily aphid-transmissible and potato virus C, according to previous workers, not at all. Thus the ability of a virus to be transmitted by an aphid is not correlated with physical or chemical properties nor with distribution in the leaf or susceptibility to secretions by aphids. Present evidence suggests that it perhaps depends on the virus particle having some special group, probably only a small part of its total constitution, that combines specifically with some component of the aphid's mouth parts.

7.32. Watson, Marion A. & Sinha, R. C. (1959). Studies on the transmission of European wheat striate mosaic virus by *Delphacodes pellucida* Fabricius. *Virology*, **8**, 139–163.

Several races of *Delphacodes pellucida* were isolated that transmit European wheat striate mosaic virus with varying degrees of efficiency. The length of the incubation period of the virus in the vectors increased as the proportion of plant-hoppers that were able to transmit infection decreased.

Efficient races of *D. pellucida* transmitted virus to a high proportion of their progeny, but nymphs of inefficient races inherited little or no virus, even from infective mothers.

Congenitally infective inbred lines of planthoppers did not become more infective after feeding on infected plants, but planthoppers that did not inherit virus could usually acquire it with about the same efficiency as that of the parent race. Females of an efficient race that became infective as a result of feeding on infected plants as nymphs, 15 days before mating, transmitted virus to eggs laid from 10 to 15 days after mating, but females fed on infected plants only during mating usually did not transmit to their progeny, though they were able to infect plants within 15 days of acquiring virus.

Infective mothers that fed on infected plants as nymphs had 40% fewer progeny than did those fed on healthy plants. Some embryos died in the egg at a comparatively late stage of development, and it is probable that the virus was pathogenic to them. The poor reproductive ability of infective females tends to eliminate the virus from colonies that are unable to renew their infectivity by feeding on infected plants.

Nematology Department

Books

8.1. Franklin, M. T. & Hooper, D. J. (1959). *Plants recorded as resistant to root-knot nematodes* (Meloidogyne *spp.*). Farnham Royal: Commonwealth Agricultural Bureaux, 33 pp.

8.2. Goodey, J. B., Franklin, M. T. & Hooper, D. J. (1959). *Supplement to the nematode parasites of plants catalogued under their hosts, 1955–58.* Farnham Royal: Commonwealth Agricultural Bureaux, 66 pp.

General Papers

8.3. Goodey, J. B. (1959). Data to be considered, observed and where possible, reported upon when presenting descriptions of new species. *Nematologica*, **4**, 211–216.

8.4. Wallace, H. R. (1959). Sugar-beet eelworm—the position today. *Sugar Beet Rev.* **28**, 83–85.

8.5. Wallace, H. R. (1959). Chrysanthemum eelworm. *Quart. Bull. nat. Chrys. Soc.* **37**, 5–10.

8.6. Wallace, H. R. (1959). Further observations on chrysanthemum eelworm. *Quart. Bull. nat. Chrys. Soc.* **39**, 7–12.

Research Papers

8.7. Fenwick, D. W. & Widdowson, E. (1959). The emergence of larvae from free eggs of the potato-root eelworm, *Heterodera rostochiensis* Woll. *Ann. appl. Biol.* **47**, 140–149.

A technique for doing hatching experiments on eggs freed from cysts is described. The form of the hatching response resembled that of eggs within cysts, but free eggs responded to the hatching stimulus more quickly. Cysts had to be soaked before extracting the eggs from them for hatching, because eggs from dry cysts, or from cysts opened or cracked before soaking, did not respond to diffusate. When free eggs and whole cysts were exposed to the same graded series of dilutions of diffusate, the log concentrations of hatching factor derived from plotting the hatching curves agreed closely.

8.8. Franklin, M. T. (1959). *Nacobbus serendipiticus* n.sp., a root-galling nematode from tomatoes in England. *Nematologica*, **4**, 286–293.

A new species of *Nacobbus*, found causing galling of the roots of tomato in a nursery in Berkshire, is described. This is the first time a member of this genus has been found outside the United States.

8.9. Franklin, M. T., Thorne, G. & Oostenbrink, M. (1960). Proposal to stabilise the scientific name of the cereal root-eelworm (Class Nematoda). *Bull. zool. Nom.* 76–85.

The arguments for using the name *Heterodera major* instead of *H. avenae* for the cereal-root eelworm are given and the use of the two names in the literature is analysed. The name *avenae* Wollenweber, 1924, is proposed in preference to *major* O. Schmidt, 1930. A new-type has been designated and is characterised.

8.10. Goodey, J. B. (1959). The excretory system of *Paraphelenchus* and the identity of the hemizonid. *Nematologica*, **4**, 157–159.

Keeping specimens of *P. myceliophthorus* in water at 4° for 3–4 months made it possible to see that, besides a ventral uninucleate cell, the excretory system has an anterior and posterior tubule in the right lateral chord. The hemizonid appears to be a ventrolateral commissure of the nervous system.

8.11. Hesling, J. J. (1959). The emergence of *Heterodera rostochiensis* from single cysts. *Nematologica*, **4**, 126–132.

New cysts of *Heterodera rostochiensis* were sieved into four size grades. The egg contents of the largest cysts varied widely. The range of egg contents decreased with decreasing cyst size, and frequency diagrams for egg contents

showed increasingly pronounced peaks. Despite random selection of the batches of 50 cysts studied in each size grade, the frequency distribution of egg contents for all grades taken together was skew and showed many cysts with between 60 and 200 eggs. Cysts in the three smaller size grades gave a higher percentage hatch than those in the largest grade. The least variable hatch was given by the second size grade (0·401–0·556 m.). Over 65% of cysts of this size range gave a hatch of over 80%.

8.12. HESLING, J. J. (1959). Some observations on the cereal-root eelworm population of field plots of cereals with different sowing times and fertiliser treatments. *Ann. appl. Biol.* **47**, 402–409.

In autumn 1953 an experiment was begun to follow changes in the cereal-root eelworm population of small plots in Shropshire. The plots were cropped with either oats, wheat, barley or rye, sown in the autumn and spring, and some plots had fertiliser. Each plot received the same treatment for 3 years; in the 4th year an indicator crop of spring oats was grown on all the plots.

Under rye and autumn-sown wheat the eelworm population fell to a level which permitted a good oat crop in 1957. Autumn-sown wheat, barley and rye gave lower eelworm populations than their spring-sown counterparts, but autumn-sown oats was the most efficient host. The order of host efficiency was oats (best), barley, wheat, rye. The eelworm populations were usually higher on plots receiving fertiliser. All oat plots, and spring-sown barley plus fertiliser, produced populations which severely damaged the 1957 oat crop.

8.13. SHEPHERD, A. M. (1959). Increasing the rate of larval emergence from cysts in hatching tests with the beet eelworm *Heterodera schachtii* Schmidt. *Nematologica*, **4**, 161–164.

The rate of emergence of larvae from cysts of *Heterodera schachtii* can be increased up to 4 times after 2 weeks by using small sieves made of polythene tubing and nylon material, which allow the cysts to be aerated all round. The rate of hatch in water is also slightly increased when sieves are used, but the total hatch is not significantly different in the two techniques. Adding fungistatic and bacteriostatic substances to the hatching medium increases further the rate of emergence and the total hatch. This may be because micro-organisms competing for oxygen are suppressed or because hatching is directly stimulated.

8.14. SHEPHERD, A. M. (1959). Testing populations of beet eelworm, *Heterodera schachtii* Schmidt, for resistance-breaking biotypes using the wild beet (*Beta patellaris* Moq.) as indicator. *Nature, Lond.* **183**, 1141–1142.

Of 8 populations of *H. schachtii* tested for their ability to infect *Beta patellaris*, single cysts able to do so occurred on 1 plant in each of 2 populations and 2 cysts on a plant in a third. Thus, resistance-breaking biotypes seem not to occur on the same scale as with *H. rostochiensis*, but the ability of individual females to multiply is important.

8.15. SHEPHERD, A. M. (1959). The invasion and development of some species of *Heterodera* in plants of different host status. *Nematologica*, **4**, 253–267.

The host–parasite relationship between *Heterodera schachtii* and 13 plant species in the families *Chenopodiaceae* and *Cruciferae* was examined. Third-stage larvae, though often few, were found in all plant species, but no fourth stage larvae were found in *B. webbiana*, *B. patellaris*, *B. procumbens*, *Hesperis* or *Matthiola*. No male was found in *B. procumbens*, *Hesperis* or *Matthiola*, and only one in *B. webbiana*. No female was found in *B. procumbens*, *B. patellaris*, *Hesperis* and *Matthiola*, very few in radish, *Chenopodium album* and *Brassica sinapis*, and only one in *B. webbiana*. *B. trigyna* was a better host than sugar beet, and the susceptible species of *Chenopodiaceae* were more efficient hosts than the susceptible species of *Cruciferae*. When hatched larvae of *H. schachtii*, *H. rostochiensis* and *H. göttingiana* were added to pots with plants

not producing a hatching factor, all species were invaded, though sometimes by very few larvae. The presence of host roots did not affect the number of larvae of *H. schachtii* invading the roots of pea, a plant that does not produce a hatching factor for this eelworm.

Factors affecting the host–parasite relationship are discussed, and a modification of Jones's classification of plants into categories of host status is suggested. The relationship is continuous rather than discontinuous, and is best expressed as a frequency. For example, when tested with an inoculum of Q larvae, P reached maturity and reproduced on variety X of plant Y. The ratio P/Q is the frequency in question, and may be 0 where X is a marginal host and Q is small, but may have a definite value when Q is large.

8.16. Shepherd, A. M. & Wallace, H. R. (1959). A comparison of the rates of emergence and invasion of beet eelworm, *Heterodera schachtii* Schmidt and pea-root eelworm, *Heterodera göttingiana* Liebscher. *Nematologica*, **4**, 227–235.

Experiments with cysts in sand under controlled moisture conditions indicate that beet eelworm has a higher emergence rate than pea-root eelworm. The invasion rate of pea-root eelworm is considerably higher than that of beet eelworm. These differences in behaviour may account for the few larvae that emerge from pea-root eelworm cysts in experiments *in vitro*; despite this, the high invasion rate populations may still increase substantially. Sampling for larvae of pea-root eelworm in a field plot containing peas showed emergence rate to be relatively low. Two experiments with beet eelworm are described showing that soil moisture may influence the production of the hatching factor from cress roots and that the rate the hatching factor diffuses through sand almost saturated with water is about 0·5 cm./day.

8.17. Wallace, H. R. (1959). Movement of eelworms. V. Observation on *Aphelenchoides ritzema bosi* on florists' chrysanthemums. *Ann. appl. Biol.* **47**, 350–360.

Adults of *Aphelenchoides ritzema bosi* tend to migrate up the stems of chrysanthemum plants in a water film with no downward flow, probably a negative geotropic response. A current of water down the stem opposes this upward movement. Mobility in different environments on the plant was determined. It was greatest in thick films of water on tissues with many epidermal hairs, as at the top of the stem and on the undersurface of leaves. Ciné films of movement in thick and thin films showed that the type of locomotion in these two environments differed greatly. Invasion of leaves via stomata was observed and the mode of entry is described. Observations on emergence of eelworms from the leaf, their movement inside the leaf and spread through the mesophyll are discussed. They emerge via the stomata, chiefly on the undersurface. When the leaf is wet about 50% of the eelworms emerge in the 1st hour. In wet weather many eelworms were recovered from the surfaces of leaves, and the eelworm probably spreads mostly in these conditions.

8.18. Wallace, H. R. (1959). The movement of eelworms in water films. *Ann. appl. Biol.* **47**, 366–370.

The beet eelworm, *Heterodera schachtii*, and the chrysanthemum eelworm, *Aphelenchoides ritzema bosi*, were observed in water films, and wave formation, wave frequency, speed and type of locomotion noted. (1) The wave frequency and speed of beet eelworm is greater in thin films than in thick; for chrysanthemum eelworm, speeds and wave frequencies were greatest in thick films; (2) chrysanthemum eelworm is more active than beet eelworm, as indicated by the higher wave frequency and speed; (3) both species form asymmetrical waves in thick films, the waves decreasing in amplitude as they pass along the body—symmetrical waves are formed by both species in thin films; (4) progress is more uniform in thin films than in thick films, where forward movement occurs as the head moves across the axis of progression. A hypothesis is given to show how the surface tension forces acting on an eelworm in a thin film determine mobility.

8.19. WALLACE, H. R. (1959). Further observation on some factors influencing the emergence of larvae from cysts of the beet eelworm, *Heterodera schachtii* Schmidt. *Nematologica*, **4**, 245–252.

The emergence curve for beet eelworm cysts in sand at controlled moisture content resembles that *in vitro*. The smaller the particle size, the higher the optimum suction for emergence. There does not appear to be a limiting suction for emergence as was suggested previously. At the optimum suction the rate of emergence may decrease with particle size. As larval emergence progresses, carbon dioxide probably accumulates and inhibits further hatch and emergence. Emergence from cyst and movement through soil pores are fundamentally the same phenomenon and obey the same factors influencing locomotion. A hypothesis is given to show how emergence is influenced by the soil environment.

8.20. WALLACE, H. R. (1960). Movement of eelworms. VI. Observations on the influence of soil type, moisture gradients and host plant roots on the migration of the potato-root eelworm, *Heterodera rostochiensis* Wollenweber. *Ann. appl. Biol.* **48**. (In the press.)

In a sandy loam, a heavy clay and a peat soil, the optimum crumb sizes for larvae of potato-root eelworm to move were 150–250 μ and 250–400 μ. Mobility in the clay and sandy loam, where there is an optimum suction for movement, was similar, but in the peat mobility increased with suction and the optimum suction was not established. Larvae may be able to move in peat at high suctions because friction between the larvae and the peat crumbs is less than in clay or sand. In a moisture gradient in sand, larvae moved to the wet end, and the number doing so increased with the steepness of the gradient. Larvae moved in sand 150–250μ diameter distances between 2 and 3 cm./day, depending on suction. As pore size increases, any upward movement in a moisture gradient is opposed by falling under gravity. In sand, where the body diameter approximates to the width of the pore, there is no response to a moisture gradient or gravity. Host roots also counteract the response to a moisture gradient; the degree of orientation to roots increased with the time the roots are in the sand. Direct observation on larvae newly emerged from cysts, in the presence of host-plant roots, suggests that larvae orientate themselves away from the root and do not reach the root by random movement. Many of the movements of eelworms seem explicable by considering the relationship between pore size, eelworm diameter and water distribution. A diagram is given showing the relationship between movement and soil factors.

8.21. WINSLOW, R. D. (1959). A note on anhydrotetronic acid as a hatching agent of the beet eelworm, *Heterodera schachtii* Schm. *Nematologica*, **4**, 237–238.

Insecticides and Fungicides Department

General Papers

9.1. WAY, M. J. (1958). The use of insecticidal seed dressings. *Rep. Rothamst. exp. Sta.* for 1958, 214–222.

9.2. WAY, M. J. (1959). Development of insect resistance to insecticides. *N.A.A.S. Quart. Rev.* **46**, 60–67.

Research Papers

9.3. BARDNER, R. (1959). Insecticidal control of wheat bulb fly larvae. *Plant Path.* **8**, 47–52.

Methods of control tested over several years included seed dressings, combine-drilling of insecticide with the seed at the time of sowing, dusting the plants and soil surface with insecticide, and spraying insecticide on the foliage.

Seed dressings of aldrin, dieldrin and heptachlor were the most effective. A very high rate of application, equivalent to 1·92 lb. active ingredient per acre, was only moderately better than 0·29 lb/acre. Combine-drilling of aldrin and dieldrin dusts at 1·5 lb/acre were effective, but less so than the seed dressings. Both seed dressings and combine-drilling have to be applied at sowing, before it is known whether the severity of the attack will justify the expense of the insecticide.

Dieldrin dust broadcast at 5 lb./acre just before the start of the attack gave promising results, but organo-phosphorus sprays applied at various times during the attack were the least successful of all the methods tried.

9.4. Elliott, M., Olejniczak, J. S. & Garner, J. J. (1959). Laboratory-scale molecular distillation of the pyrethrins. *Pyrethrum Post*, **5** (2), 8–18.

The conditions of molecular distillation to give a pale-coloured distillate containing 60–70% total pyrethrins were determined. The undistilled residue contains less than 10% pyrethrins, and no thermally isomerised pyrethrins I and II can be detected.

9.5. Last, F. T. (1959). Effect of cotton leaf resistance factors on the spread of *Xanthomonas malvacearum* (E.F.Sm.) Dowson in the Gezira, Sudan. *Emp. Cott. Gr. Rev.* **36** (3), 187–195.

Knight's cotton leaf resistance factors retarded the spread of *X. malvacearum* in field crops in 1956–58 to much the same extent as they retard the development of individual lesions. Of the factors and combinations of factors tested, B_2 was the least effective in preventing the spread of disease and B_2 and B_3 combined were intermediate, while combinations with B_{6m} were the most effective. B_2B_{6m} and $B_2B_3B_{6m}$ varieties did not differ appreciably from each other.

Recently-irrigated plants of the B_2B_3 derivative (BAR 14/25) of Domains Sakel (*Gossypium barbadense*) became more diseased after a rainstorm than plants unirrigated for at least 6 days.

9.6. Last, F. T. (1959). Leaf infection of cotton by *Xanthomonas malvacearum* (E.F.Sm.) Dowson. *Ann. appl. Biol.* **47**, 647–657.

X. malvacearum spread more rapidly along vascular tissue than into mesophyll when inoculated to the main veins of susceptible cotton leaves. The extent of spread varied with the concentrations of inocula, tissue age and cotton variety.

Increasing concentrations of inocula accelerated the initial spread of disease.

Bacteria spread more rapidly in young leaves than in old —increasing age greatly decreased disease in the mesophyll. The initial invasion was quicker in young leaves of young plants than in young leaves of old plants.

Three types of behaviour, according to the host's reaction, distinguish Knight's resistance factors: (*a*) where *X. malvacearum* spread extensively along veins and into mesophyll of plants containing B_3 and B_5; (*b*) where it was restricted to the point of inoculation in plants containing B_4, B_9 and combinations with B_{6m}; and (*c*) where it spread along veins but not appreciably into mesophyll in varieties containing B_2 and B_2B_3.

From this and 4 other different types of tests, factors B_2 and B_3 seem to increase mesophyll resistance, but only B_2 gives appreciable vascular resistance. Further, the vascular bundles in varieties with B_2 seem to be surrounded by an additional " barrier " which resists *X. malvacearum*.

9.7. Last, F. T. (1959). Effect of *Xanthomonas malvacearum* (E.F.Sm.) Dowson on cotton yields. *Emp. Cott. Gr. Rev.* **37**.

As many cotton plants were infected by *Xanthomonas malvacearum* spread from infectors sown simultaneously with the rest of the plot as from infectors planted 3 weeks later. Yields, however, were only affected by bacteria from the earlier-sown infectors. Weights of seed cotton decreased by 19% (without affecting the Ginning-out-Turn), and harvest was significantly delayed.

9.8. MACFARLANE, I. & LAST, F. T. (1960). Some effects of *Plasmodiophora brassicae* Woron. on the growth of the young cabbage plant. *Ann. Bot. N.S.* (In the press.)

(For summary see No. 7.27 above.)

9.9. WARD, J., GILLHAM, E. M. & POTTER, C. (1959). A thermal preference method of bioassay of the toxicity of insecticidal films to houseflies. *Bull. ent. Res.*

Methods used to confine insects to the test-surface during exposure to insecticidal deposits are reviewed, and their limitations discussed.

A temperature preference method of inducing houseflies to remain on a treated surface is described, and the apparatus is illustrated. The treated surface forms the floor of a chamber; it is maintained at a higher temperature than the walls and lid. The flies are introduced with a plunger device.

The variance in mortality among groups of insects given the same exposure was determined in three experiments. In the first, plates sprayed with a crystalline suspension of DDT were used immediately after spraying, and the variance was high. In the second, the same set of plates was used 24 hours later, and the results were not significantly heterogeneous. In the third, plates carrying a deposit of DDT in liquid paraffin were used, and the results were just significantly heterogeneous at the 5% level of probability. The heterogeneity is thought to come from variations in the degree of activity of the houseflies while on the test-surface; it was too small to affect probit lines obtained with the apparatus.

Nine successive experiments, in which the LD-50 of DDT/liquid paraffin on glass plates was determined, gave a range of results from 0·65 to 1·45 μg./cm.^{2} of DDT and probit line slopes in the range 2·8 6·2. One of the lines was significantly heterogeneous.

In seven separate experiments to determine the toxicity of DDT emulsion sprayed on cabbage leaves, the probit lines were too steep for calculation by the normal method, but all the points fell between parallel lines intersecting the 50% mortality abscissa at 1·4 and 2·7 μg./cm.^{2}—no greater than the usual variation in resistance between different cultures of test-insects.

The behaviour of some other insect species in the test chamber was observed. The apparatus would probably be suitable for use with *Blatella germanica*, but some species failed to respond to the temperature gradient and others were too small for the apparatus as described.

9.10. WAY, M. J. (1959). The effects of freezing temperatures on the developing egg of *Leptohylemyia coarctata* Fall. (Diptera, Muscidae) with special reference to diapause development. *J. Insect Physiol.* (In the press.)

The later stages of diapause in the egg of *L. coarctata* are completed rapidly at −20° C. to −24° C. At −24° C. diapause is completed about 180 times faster than at −6° C. and about 80 times faster than at 3° C. These results suggest that there are at least two phases in diapause development—an initial synthesis, perhaps of neurohormone, which will not occur at −18° C. to −24° C. This is followed by a process ending in release of the synthesised material which is greatly accelerated by relatively short exposures to −20° C. to −24° C.; longer exposures kill the eggs probably because they freeze.

9.11. WAY, M. J. (1959). Experiments on the mode of action of dieldrin seed dressings against seedling attack by the larval frit fly, *Oscinella frit* L. *Ann. appl. Biol.* **47**, 802–808.

In glasshouse experiments and in a small field trial fewer newly hatched frit-fly larvae were killed when dieldrin-treated seed was sown deeply than when sown $\frac{1}{4}$–$\frac{1}{2}$ inch deep. Shallow sowing probably puts the insecticide where the larvae from eggs in the soil are likely to meet it before they attack the plant. Larvae hatching from eggs on the plant are probably unaffected by contact action. There was little evidence that frit-fly larvae are killed inside the oat shoot by systemic action of dieldrin translocated from the seed. This is not from any factor specific to oats because frit-fly larvae also survived in wheat from seed dressed with doses of dieldrin that can kill almost all wheat bulb fly larvae (*Leptohylemyia coarctata* Fall.) by systemic action.

9.12 WAY, M. J. (1959). Experiments on the mode of action of insecticidal seed dressings especially against *Leptohylemyia coarctata* Fall., Muscidae, the wheat bulb fly. *Ann. appl. Biol.* **47**, 783–801.

Certain chlorinated hydrocarbon insecticides applied as seed dressings to wheat can kill wheat bulb fly larvae either by contact or by systemic action. Shallow sowing favours contact action because the larvae are likely to pass close to the treated seed on their way to attack the shoot. It is not known whether the larvae are killed directly by contact action or whether they die of starvation after being deterred. Wheat bulb fly larvae tunnel within the shoot and may damage it severely before they are killed by the systemic action of aldrin or dieldrin seed-dressings. Close contact between the seed-dressing and the seed apparently favours the uptake of dieldrin and aldrin by the plant: systemic action is also favoured by sowing the seed shallowly and by increasing the dose of insecticide adhering to the soil.

Onion fly larvae *Delia antiqua* Meig. enter the onion bulb close to the position of the seed, and thus are likely to be killed by contact with the insecticide on the seed. There was no evidence that dieldrin seed-dressings act systemically against onion fly larvae.

9.13. WAY, M. J. (1959). The effect of temperature, particularly during diapause, on the development of the egg of *Leptohylemyia coarctata* Fallen (Diptera: Muscidae). *Trans. Roy. Ent. Soc.* **3**, 351–364.

The eggs of *L. coarctata* Fallen are usually laid on bare soil in August and hatch during the following January–March.

The embryo apparently becomes fully developed during pre-diapause morphological development which merges imperceptibly into the diapause stage. Diapause ends by January, and the eggs begin to hatch shortly afterwards when the temperature is above 0° C.

Although eggs near the surface experienced much greater temperature fluctuations than those deeper in the soil, all hatched at the same time.

Within the normal temperature range, the lower and upper limits for the different stages of development are: pre-diapause morphological development —between 0°–3° C. and over 30° C.; diapause physiological development— 6° C. and 12° C.; post-diapause development (re-activation and hatching)— 0° C. and over 30° C. The optimum constant temperature for diapause development is about 3° C. The egg can develop through all stages at constant temperatures between 3° C. and 12° C.; the optimum is about 7° C. Development is accelerated in some eggs by transferring them in the middle of their diapause to 30° C. or 35° C., for 1–7 days, but it is stopped or reversed by an interval of 2–4 weeks at 20° C.

Development can proceed at the beginning of diapause, and to a lesser extent towards the end, at a temperature above the upper limit for the intervening stages. This suggests that the temperature optimum for diapause may vary as development proceeds.

Diapause development at −20° C. may be as fast as at 3° C. This is not ecologically significant, but may help towards understanding the physiology of diapause.

Entomology Department

General Papers

10.1 BARNES, H. F. (1959). Gall midges (Cecidomyidae, Diptera) living at the base of grasses. *J. Sports Turf Res. Inst.* **9**, 430–436.

10.2. GERARD, B. M. (1959). Earthworms in farm and garden. *Turf for Sport*, **3** (6), 11–14.

10.3 MELLANBY, K. (1959). Life at low temperatures. *Advanc. Sci., Lond.*, **15**, 409–417.

Research Papers

10.4 Banks, C. J. (1959). Experiments with suction traps to assess the abundance of Syrphidae (Diptera), with special reference to aphidophagous species. *Ent. exp. & appl.* **2**, 110–124.

Preliminary information on the abundance of some common species of Syrphidae was obtained from the catches in 5 suction traps during the summers of 1951, 1952 and 1953. Six of the eight "abundant" species were aphidophagous.

The numbers of the individual species recorded varied from year to year, with the time of year and from place to place.

Although the catches could not be correlated with the immediate weather, the large differences between them could be associated with the differences in the general weather of the 3 years. Syrphidae were few in the spring, although most species showed a small peak of numbers then, and maximum catches of nearly all species were in August.

At two localities the abundance of individual species and the composition of the catches differed greatly. Where the vegetation was varied, Syrphidae were more diverse and more abundant than where it was uniform. Some species occurred in one locality but not in the other. The size and composition of the catch were not obviously affected by the kind of vegetation immediately around a trap.

10.5. Banks, C. J. & Nixon, H. L. (1959). The feeding and excretion rates of *Aphis fabae* Scop. on *Vicia faba* L. *Ent. exp. & appl.* **2**, 77–81.

The feeding and excretion rates of nymphs of *Aphis fabae*, feeding on young leaves of *Vicia faba*, were studied, using host plants grown in water culture and made radioactive with 32p. Little sap was ingested at first, but the rate of ingestion increased rapidly between 12 and 16 hours. The maximum rate of feeding was estimated at 0·2 mg. sap/hour, an uptake of 59% of the mean body weight of the insects per hour. The results are discussed in relation to other recent work on aphid feeding and excretion.

10.6. Barnes, H. F., Miller, B. S. & Arnold, M. K. (1959). Some factors influencing the emergence of overwintering Hessian Fly larvae. *Ent. exp. & appl.* **2**, 224–239.

Overwintering fully-fed hessian fly larvae in puparia respond to temperature and relative humidity changes progressively faster as the normal time of pupation and emergence in the spring approaches. Frost does not speed up emergence.

A constant temperature of 15° or 20° C. at 95% R.H. is recommended for producing midges for experiments from overwintering hessian fly puparia.

10.7. Barnes, H. F., Miller, B. S. & Arnold, M. K. (1959). The susceptibility of Atle wheat to attack by the Wheat Blossom Midges. *Plant Path.* **8**, 143–144.

Atle is sometimes as susceptible as other varieties.

10.8. Dobson, R. M. (1959). Preliminary observations on the behaviour of the adult Wheat Bulb Fly *Leptohylemyia coarctata* (Fall.) using the field-cage-marking technique. *Anim. Behav.* **7**, 76–80.

The behaviour of wheat bulb fly was observed over two 24-hour periods during July 1957, using individually marked flies confined in a large field cage standing in a wheat crop. Flies occurred on the fabric of the cage, on the wheat, on flowering grasses and less often on various weeds (some of which were abundant), and on the ground. Differences in the proportions of the sexes on the cage and on various parts of the wheat plants reflected differences in their behaviour.

Females were very active shortly before nightfall, but after dark both sexes

became quiescent (although some activity including flight persisted) and adopted a characteristic " head-upward " posture. At daybreak activity was resumed.

The technique could be developed into a valuable one for studying behaviour in the field.

10.9. Dobson, R. M. (1959). Notes on the taxonomy and occurrence of *Carpophilus* Stephens. (Col. Nitidulidae) associated with stored products. *Ent. mon. Mag.* **95**, 156–158.

Type specimens of *Carpophilus dimidiatus* (F.) and *Carpophilus mutilatus* Er. are designated and *C. luridus* Murray is shown to be a synonym of *C. mutilatus* Er. Recent records of *Carpophilus* species found on stored produce are tabulated.

10.10. Dobson, R. M. (1960). Hatching of the egg in the Cabbage Stem Flea Beetle *Psylliodes chrysocephala* (L.) (Col. Chrysomelidae). *Ent. mon. Mag.*

The egg bursting mechanism and manner of hatching of the flea beetle *Psylliodes chrysocephala* (L.) are described.

10.11. Dobson, R. M. (1960). The immature stages of the Flea Beetles *Psylliodes cuprea* (Koch) and *Psylliodes chrysocephala* (L.) (Col. Chrysomelidae.) *Ent. mon. Mag.*

The immature stages of *Psylliodes chrysocephala* (L.) and *Psylliodes cuprea* Koch are described, figured and compared.

10.12. French, R. A. (1959). Migration records 1958. *Entomologist*, **92**, 164–176.

10.13. (Entwistle, P. F.), Johnson, C. G. & (Dunn, E.). (1960). New pests of Cocoa (*Theobroma cacao* L.) in Ghana following applications of insecticides. *Nature, Lond.* **184**, 2040.

10.14. Long, D. B. (1959). Observations on adult weight and wing area in *Plusia gamma* L. and *Pieris brassicae* L. in relation to larval population density. *Ent. exp. & appl.* **2**, 241–248.

Crowding of lepidopterous larvae decreases weight and wing dimensions in the resulting adults and possibly contributes towards migration by its effect on form and function. The ratio of total weight to wing area is often termed " wing loading ", and this ratio increases with different species of flying creatures of increasing weight.

The effect of larval crowding on body weight and wing loading in *Plusia gamma* L. and *Pieris brassicae* L. was studied by contrasting freshly emerged adults from solitary and crowded larval cultures. Crowding decreased weight and wing area disproportionately, thereby decreasing wing loading. Within each species and sex wing loading decreased with decreasing emergence weight, and this partly explained the effect of crowding on wing loading.

In *P. gamma* the fore-wing was larger than the hind-wing. Nevertheless, the fore-wing was the more affected by crowding, and more in the female than the male. Temperature also affected weight and wing area. In solitary cultures warmer weather principally decreased male weight and hind-wing area, whereas fore- and hind-wing areas of the female were more affected, consequently wing loading decreased in the male and increased in the female.

In *P. brassicae* the hind-wing is the larger, and decreased more with crowding. Crowding did not appear to affect the sexes differently, but the results suggested that the effect may be accentuated in the male and lessened in the female at lower temperatures. As with *P. gamma*, warmer temperatures decreased weight and wing area in *P. brassicae*, but wing area was the more affected, so wing loading increased in both sexes. Crowding, however, accentuated the effect of temperature on weight, thereby decreasing wing loading. Thus, in both species decreases in weight and wing area with warmer temperatures were not identical with those of crowding.

10.15. Mellanby, K. (1960). Acclimatisation affecting the position of the cold and heat death points of larvae of *Aedes aegypti* (L.). *Bull. ent. Res.* **50**, 821–823.

In experiments with *Aedes aegypti* (L.), fourth-stage larvae bred at 30° C. survived exposure to 0·5° C. for 7 hours, but none recovered after exposure for 17 hours, although nearly all those from the same culture that had been acclimatised for 24 hours to 18° or 20° C. did so. No such effect followed acclimatisation at 10° C., at which larvae are in chill coma. Larvae acclimatised at 18° C. survived exposure to 5° C. for longer than did those from 30° C. The thermal death point, for a 1-hour exposure, was 42° C. for larvae acclimatised at 30° C. but rose to 44° C. for larvae acclimatised to 37° C. It is concluded that the effects of high or low extremes of temperature may be modified by a brief period of acclimatisation at a less extreme temperature.

10.16. Mellanby, K. (1960). The biological importance of the invertebrate soil fauna. *Soils & Fert.* **23**, 8–9.

Invertebrates metabolise more slowly than warm-blooded vertebrates. Laboratory measurements of invertebrate metabolism may give results much higher than those obtaining in the soil. The biological importance of vertebrates, which is related to their metabolic rate, may easily be overestimated.

10.17. Mellanby, K., French, R. A. & Riches, J. (1960). Herbicide spray and frit fly attack on oats. *Ent. exp. & appl.* **2**, 319–320.

Oats sown 11 April 1959 had a similar tiller attack by frit fly in areas sprayed with CMPP and in unsprayed areas.

10.18. Murphy, P. W. (1959). Soil faunal investigations. *Rep. For. Res.* for 1958.

10.19. Raw, F. (1959). Estimating earthworm populations by using formalin. *Nature, Lond.* **184**, 1661.

Earthworm populations estimated by using dilute formalin to make the worms come out of the soil are compared with estimates obtained by using potassium permanganate solution and by hand-sorting soil samples. Formalin is more efficient than potassium permanganate solution, but less efficient than hand-sorting soil samples, except for estimating *Lumbricus terrestris*. This species burrows too deeply for soil sampling to be practicable, but seems to be extracted very efficiently by formalin.

10.20. Raw, F. (1960). Field studies on wheat bulb fly infestations. *Ann. appl. Biol.* **48**, 145–155.

Two experiments on commercial farms in Essex studied the effect of tilth, cultivation and seed rate on wheat bulb fly infestation and the effect of infestation on yield. Heavier infestations developed on rough fallows and those cultivated during the oviposition period than on smooth fallows and those not cultivated during the oviposition period. These results confirmed those of an earlier experiment done at Rothamsted. At each level of infestation more larvae survived on plots sown at 3 bushels/acre than on plots sown at $\frac{2}{3}$ or 1 bushel/acre. Although some plots had a high larval population, no effect of infestation on yield was observed even at the lower seed rates. This is attributed to early sowing. The extent to which the cultural treatments studied can be used to control wheat bulb fly infestations is discussed.

10.21. Stephenson, J. W. (1958). Aldrin controlling slug and wireworm damage to potatoes. *Plant Path.* **8**, 53–54.

Applying 1¼% aldrin dust at either 480 lb./acre or 240 lb./acre immediately before planting significantly decreased damage by slugs and wireworms.

10.22. Taylor, L. R. (1959). Abortive feeding behaviour in a black aphid of the *Aphis fabae* group. *Ent. exp. & appl.* **2**, 143–153.

A black *Aphis* sp. on Tropaeolum can be separated, morphologically, from *A. fabae* Scop. In controlled experiments this aphid, both winged and wing-

less forms, actively selects *Vicia faba* as a host plant, settles to feed and reproduce, but always dies prematurely. Offspring also soon die. The aphid is unable to take up plant sap from beans. The behaviour associated with host-plant selection is not adjusted to its feeding requirements.

10.23. TAYLOR, L. R. (1960). Mortality and viability of insect migrants high in the air. *Nature, Lond.*

Insects were collected by nets at heights from 1,000 to 5,000 feet, between 09.00 and 16.00 hours in June, July, August and September, at Cardington, Bedfordshire. 97% of the 1,610 insects caught were alive and undamaged. Living offspring were obtained from:

Cabbage aphid, *Brevicoryne brassicae* L.
Peach-potato aphid, *Myzus persicae* Sulz.
Bean aphid, *Aphis fabae* Scop.
Frit fly, *Oscinella frit* L.
The hessian fly group, *Mayetiola* sp., possibly *destructor* Say.

This establishes that insects migrating at high levels in normal summer weather over England are alive and viable.

10.24. TAYLOR, L. R. (1960). The distribution of insects at low levels in the air. *J. anim. Ecol.*

Records of insects caught on sticky traps and in nets at several heights up to 30 feet were examined and the density distribution estimated in relation to height.

The insects concerned are all small; thrips, aphids, psocopterons, frit-fly and coccinellids. Their distribution appears to be consistent with that found for similar insects at greater heights.

Density diminishes regularly as height increases, except that gradients may change at 20–25 feet and between 30 and 50 feet.

These are probably the levels up to which such small insects fly in still air, and the predominance of winds above their flight speed is an over-riding influence that produces the generally regular profile when all weather conditions are taken together. Suction-trap catches, which show a mean density for all insects 3 times as great at 5 as at 30 feet, support this conclusion.

Larger insects, e.g., moths, behave differently; suction-trap catches show they can select a particular height of flight.

Catches on sticky traps were converted to densities by using a general wind-speed profile, which although open to some criticism is not sufficiently in doubt to affect the main conclusions.

The curve distributions of insect numbers often produced when sticky-trap catches are plotted against height and give maximum values at different heights on different occasions or for different species, are a product of the wind-speed and insect-density profiles, i.e., a function of the type of trap used rather than of the behaviour of the insect.

10.25. ZAHER, M. A. & LONG, D. B. (1959). Some effects of larval population density on the biology of *Pieris brassicae* L. and *Plusia gamma* L. *Proc. R. ent. Soc.* (A) **34**, 97–109.

Although crowding in *P. gamma* prolonged the pupal period, it shortened the larval and pre-oviposition periods so much that the total developmental period from hatching to egg-laying was shorter than under solitary conditions. In both larval treatments a long larval period was followed by a relatively short pupal period, and a short preoviposition period by the laying of many eggs. The subsequent fecundity was greater in crowded cultures, though under both conditions of culture more than one-half of the eggs were laid by slightly more than 20% of the females.

In *P. brassicae* the shorter larval period in crowded cultures was followed by a shorter pupal, but preoviposition period and the total developmental period was, however, less, with fewer eggs in a cluster.

In both species the mean egg weight was lighter in crowded cultures. The adult lifespan of the male in *P. gamma* and of the female in *P. brassicae* tended to be prolonged by crowding. Crowding larvae of *P. gamma* did not influence either the percentage of sterile females or their lifespan.

Bee Department

General Papers

11.1. Bailey, L. (1959). Recent research on the natural history of European Foul Brood disease. *Bee World*, **40**, 66–70.

11.2 Butler, C. G. (1959). Queen substance. *Bee World*, **40**, 269–275.

11.3 Free, J. B. (1959). The transfer of food between the adult members of a honeybee community. *Bee World*, **40**, 193–201.

11.4. Free, J. B. & Spencer-Booth, Yvette. (1959). Temperature regulation by honeybees. *Bee World*, **40**, 173–177.

11.5. Simpson, J. (1960). Problems of swarming behaviour. *Rep. cent. Ass. Brit. Beekeep. Ass.*

Research Papers

11.6. Bailey, L. (1959). An improved method for the isolation of *Streptococcus pluton*, and observations on its distribution and ecology. *J. Insect. Path.* **1**, 80–85.

Streptococcus pluton was isolated, on a special agar, more easily and in greater abundance from dried smears of mid-gut contents of honeybee larvae with European Foul Brood disease than from fresh material. *S. pluton* remains viable in such smears for at least 15 months at room temperature. Viable *S. pluton* is smeared over cell walls of brood comb in the faeces of infected larvae that survive and pupate. *S. pluton* was isolated from larval remains from colonies suspected of having European Foul Brood disease from Tanganyika, Norway, California and Southern England.

11.7. Bailey, L. & Lee, D. C. (1959). The effect of infestation with *Acarapis woodi* (Rennie) on the mortality of honeybees. *J. Insect. Path.* **1**, 15–24.

In laboratory and field tests infestation increased mortality of the oldest and most heavily infested bees only. This corresponds with lack of signs of infestation in heavily infested colonies except at the end of winter when the population is senile. Restricted development of brood in summer was associated with increased infestation.

11.8. Butler, C. G. (1959). The source of the substance produced by queen honeybee (*Apis mellifera* L.) which inhibits development of the ovaries of the workers of her colony. *Proc. R. ent. Soc. Lond.* (*A*). **34**, 137–138.

Development of the ovaries of the worker bees of a colony is normally inhibited by a substance produced by the queen and distributed over her body surface, from which the workers obtain it. The same or an analogous substance normally inhibits workers from rearing queens. Both the substance which inhibits queen rearing and that which inhibits ovary development are produced in the queen's mandibular glands.

11.9. Butler, C. G. (Callow, R. K. & Johnson, Norah C.). (1959). Extraction and purification of " queen substance " from queen bees. *Nature, Lond.* **184**, Suppl. 24, 1871.

A method of extracting and purifying queen substance in ethanol extracts of queens' heads is described. The waxy crystals, which inhibit queen rearing by worker bees, appear to be an $\alpha\beta$-unsaturated carboxylic acid, containing an unconjugated carbonyl group.

11.10. FREE, J. B. (1959). The effect of moving colonies of honeybees to new sites on their subsequent foraging behaviour. *J. agric. Sci.* **53**, 1–9.

Groups of colonies were moved to crops: before any flowers were open, when 5–15% were open, when flowering was near its peak. Colonies moved to the crop after flowering had begun provided more pollinators than those moved earlier.

11.11. FREE, J. B. & SPENCER-BOOTH, YVETTE. (1959). Observations on the temperature regulation and food consumption of honeybees (*Apis mellifera*). *J. exp. Biol.* **35**, 930–937.

Bees were kept in groups ranging from 10 to 200 bees, at temperatures from 0° to 40° C. At 40° bees in groups of 200 had a higher mortality than those in smaller groups. At 25°–35° mortality was low and similar in all groups. Below 25° the larger a group, the longer it survived. Temperatures of all groups increased with that of their environment; the larger a group, the higher its temperature. The difference between the temperature of a group and that of its environment decreased as the temperature of the latter increased, until at 35°–40° the temperatures of groups of all sizes were slightly below those of the environment. Between 20° and 40° the percentage of bees in a group which were clustering was directly related to the size of the group; bees in small groups scarcely clustered at all. At or below 15° about the same high percentage of bees clustered in all groups. As environmental temperature decreased food consumed per bee increased. Very little water was taken at 25° or lower, but at 35° and above a lot was taken.

11.12. SIMPSON, J. (1959). Variation in the incidence of swarming among colonies of *Apis mellifera* throughout the summer. *Insectes soc.* **6**, 85–99.

Observations were made throughout the summer of the quantity of adult bees and brood, the numbers of queen-cell cups and the incidence of swarm preparations, in colonies. Comparison of these data with long-term averages of temperature and nectar availability showed that in the summer months the season of maximum breeding and swarming was more closely related to food supply than to temperature or length of day. The possibility that a physiological rhythm was also involved could not be excluded. Swarm preparations appeared to be a cause of, rather than caused by, a decline in brood rearing or the ratio of brood to adult bees.

11.13. SIMPSON, J. (1959). The male genitalia of *Apis* species. *Nature, Lond.* **185**, 56.

The male genitalia of honeybees from tropical Africa appear identical with those of European bees (*A. mellifera*), but both differ from the closely allied species *A. indica* (from Ceylon). Specimens from intermediate regions have not yet been obtained. The male genitalia of *A. dorsata* and *A. florea* are also described.

11.14. SIMPSON, J. (1960). The functions of the salivary glands of *Apis mellifera*. *J. Ins. Physiol.* (In the press.)

Worker bees dissolve dry sugar, clean their queen's body and possibly soften or lubricate materials being chewed, with the watery secretion of their labial glands. A small amount of oil is produced and accumulates in these glands: what little is discharged adheres to the tongue hairs and is not mixed with the food: its function is obscure. Secretion of the mandibular glands is discharged by a movement of the hypopharyngeal plate, acting through a tendon, on the mouth of the gland. It is a suspension of acid globules, insoluble in water and in some lipoid solvents but soluble in alcohol, glycol, etc. The secretion of the mandibular glands is not used in chewing. Salivary invertase comes only from the hypopharyngeal glands.

11.15. (Callow, R. K., Johnston, Norah C.) & Simpson, J. (1959). 10-hydroxy-Δ^2-decenoic acid in the honeybee (*Apis mellifera*). *Experientia*, **15**, 421.

Comparison of physico-chemical properties showed that the secretion of the mandibular glands of worker bees consists largely of 10-hydroxy-Δ^2-decenoic acid, the main lipoid component of larval food.

Statistics Department

Book

12.1. Yates, F. (1960). *Sampling methods for censuses and surveys.* 3rd Edition. London: Griffin.

A new chapter describing the applicaton of electronic computers to the analysis of censuses and surveys has been added. A general system for the specification of survey analyses on such computers is described.

General Papers

12.2. Healy, M. J. R. (1960). The uses of automatic computers in studies of growth and physique. *Proc. 1959 int. Conf. med. Electronics.* (In the press.)

12.3. Simpson, H. R. (1960). The analysis of survey data on an electronic computer. *Proc. 1959 int. Conf. med. Electronics.* (In the press.)

12.4. Yates, F. (1959). Obituary: Wilfred Leslie Stevens. *J. R. statist. Soc. A*, **122**, 403–404.

12.5. Yates, F. (1959). Mathematics in biological and agricultural research. *Proc. Liverpool Math. Conf.* (In the press.)

12.6. Yates, F., Healy, M. J. R. & Lipton, S. (1959). L'analyse des expériences répétées sur calculatrice électronique. *Rev. Stat. appl.* **7**, 47–75. (Translated from *J. R. statist. Soc. B*, **19**, 234–254, (1957).)

Research Papers

12.7. (Alexander, W. H.) & Leech, F. B. (1960). A quantitative evaluation of some factors affecting the non-fatty solids of cows' milk. *J. Dairy. Res.* **27**, 19–32.

The statistical analysis of data from problem and control herds showed that most of the differences in level of S.N.F. in these two groups could be accounted for by differences in the proportions of old cows, by breed differences, by differences in the total cell count of the milk and by a seasonal effect that occurred only in the problem herds. The effect of conception late in lactation is shown.

The herd age and average calving intervals are largely under the control of the owner, but there is no evidence that high cell counts can be controlled effectively by means other than lowering the herd age. Clinical mastitis was clearly associated with high cell counts, and tended to be most frequent in old cows, so that lowering the herd age would be expected to affect three factors—age, cell count and mastitis—all of which tend to lower S.N.F.

The remaining effect (seasonal/feeding) was unchanged by improvements in feeding suggested to the owners; its total effect was small, but it merits further investigation.

12.8. Boyd, D. A. (1960). Sampling surveys in agriculture. *N.A.A.S. quart. Rev.* **12**, 108–115.

The article deals mainly with those types of survey with which members of the National Agricultural Advisory Service are likely to be associated, and

describes the kind of information which can be obtained from them. The relative advantages of postal surveys and surveys by personal visit are discussed, sampling procedures are outlined and hints are given on drawing up the questionnaire and collecting and recording the information.

12.9. Chisci, G. C. & Lessells, W. J. (1960). Relative productivity of six local varieties of lucerne in Northern Italy. *Euphytica*, **9**.

The yields of 6 varieties of lucerne are compared in 6 experiments in Northern Italy; cuts were taken over a 3-year period. Each variety possessed an advantage in the locality of its origin; otherwise differences between varieties were consistent from one centre to another.

12.10. Church, B. M. (1959). Fertiliser practice surveys in England and Wales. *Agriculture, Lond.* **66**, 389–395.

Methods used in fertiliser practice surveys in England and Wales are described. The value of information on how farmers use fertilisers, to the advisory services, to farmers themselves and to industry, is illustrated by discussing results from a series of surveys in East Shropshire. Some information on recent trends in cereal manuring in England and Wales is summarised.

12.11. Church, B. M. (Gough, H. C. & Southey, J. F.). (1959). Soil sampling procedure for potato root eelworm cysts. *Plant Path.* **8**, 146–151.

A series of co-operative experiments to determine the sampling errors when estimating field populations of *Heterodera rostochiensis* Woll is described. Estimates are made of the accuracy obtained from different samples, and methods are recommended for routine sampling. Although sampling errors are greater than with cereal-root eelworm, much the same recommendations apply. The results show the advantage of systematic sampling on a rectangular grid and of taking repeat samples from the same points when following trends.

12.12. Church, B. M. & (Woodford, E. K.). (1960). A pilot survey of herbicide practice in N.W. Oxfordshire. *Farm Economist.* (In the press.)

This paper describes a pilot survey of 83 farms, made by the A.R.C. Unit of Experimental Agronomy, Oxford, to discover how much information could be obtained on herbicide practice and its effects by interviewing farmers.

12.13. Healy, M. J. R. (1959). The analysis of field experiments on an electronic computer. *Biomet. Z.* **1**, 210–214.

A summary of the methods of analysis of experiments on the Rothamsted electronic computer, together with a catalogue of the programmes at present available.

12.14. (Leslie, P. H.) & Gower, J. C. (1960). The properties of a stochastic model for the predator–prey type of interaction between two species. *Biometrika.* (In the press.)

A stochastic model of a predator–prey system is studied by numerical methods.

In the model considered the birth-rates of both species are kept constant throughout, any change in the numbers of the predator affects the death rate of the prey. The main concern is to investigate the behaviour of the system in the region of the stationary state, and to estimate the chances of random estimation for one or other of the two species. Theoretical formulae are obtained for first approximations to the variances and covariances of the two species numbers for a system in the region of the stationary state.

A set of parameters governing the system is chosen so that the population numbers of both species are sufficiently large to make the chances of random extinction of either species negligible. Numerical results obtained lead to variances and covariances that agree well with the theoretical approximations. A further contrast with theory is made between the mean recurrence time of particular population numbers, and satisfactory agreement is found here too.

Some numerical results are obtained and discussed for systems where the chance of random extinction is no longer negligible.

The remainder of the paper discusses various ways in which the probability of both species persisting may be increased.

12.15. PATTERSON, H. D. (1960). A further note on a simple method for fitting an exponential curve. *Biometrika*, **47**.

A method is presented for estimating ρ in the equation $y = \alpha - \beta\rho^x$ for up to $n = 12$ equally spaced values of x from the root of a quadratic equation in r with coefficients given by linear functions of the y_x. Unless ρ is very small and n large these estimates have very high efficiencies and are good approximations to the least-squares estimates r. The agreement with r is particularly good when $n = 4$. Details are also given of a similar method for the case in which $x = 0$, 1, 2 and 4.

12.16. PATTERSON, H. D. (1959). An experiment on the effects of straw ploughed in or composted on a three-course rotation of crops. *J. agric. Sci.* (In the press.)

This paper deals with the results of a long-term experiment on the effects of wheat straw (ploughed in or composted) and NPK fertilisers on yields of barley, sugar beet and potatoes grown in a three-course rotation.

All the effects of straw obtained in this experiment can be attributed to changes in the supplies of available nutrients; no benefits appear to have been obtained through improved soil structure or increased organic matter content. The most important changes in nutrient supplies were: (1) losses of soil nitrogen or nitrogen fertiliser immobilised by the straw, and (2) gains of potassium from the straw.

When the straw was ploughed in directly about 0·08 cwt. N fertiliser applied to crops for each ton of straw was sufficient to overcome losses in yield due to immobilisation of nitrogen. The effects of the potassium in the straw were about the same as the effects of equivalent amounts of K fertiliser added to the crop.

Compost made with NP fertiliser and straw and ploughed in with K fertiliser gave very poor results. All the N fertiliser (0·15 cwt. N for each ton of straw) was either lost through drainage or immobilised by the straw; also more than one-half of the potassium in the straw was lost in composting.

There is some evidence that the immobilised nitrogen added to the store of slowly available nitrogen; none of this became available, however, in the first or second year after application.

12.17. PATTERSON, H. D. & LIPTON, S. (1959). An investigation of Hartley's method for fitting an exponential curve. *Biometrika*, **46**, 281–292.

The efficiencies and biases of the estimates of ρ in the equation $y = \alpha - \beta\rho^x$, obtained by the method of Hartley, were examined numerically using general formulae derived in an earlier paper by Patterson. Whereas Hartley's method generally leads to estimates having relatively high efficiencies and small biases, and can therefore be regarded as adequate for many purposes, the same conclusion does not hold for similar methods sometimes used in place of the original Hartley method.

12.18. WESTMACOTT, M. H. & (LINEHAN, P. A.) (1960). Measurement of uniformity in seed bulks. *Proc. 1959 Conf. Seed Testing Assoc.* (In the press.)

A new measure of imperfection in the mixing of different batches of seed is developed.

12.19. (WITHERS, F. W.), (PECK, E. F.) & LEECH, F. B. (1959). A survey of diseases and losses in dairy cattle in Wiltshire and Devonshire.

The relation of disease to culling and wastage in Wiltshire and a part of Devon is analysed, and estimates are obtained of depreciation in the market value of cows affected by the more common diseases. These estimates lead

to a rough assessment of the relative economic importance of the diseases studied.

The principal causes of morbidity and their incidence are summarised. Some differences between counties and between the two years are shown and discussed.

Characteristics of the herds in the two areas and within the major land-use regions of each area are shown, and estimates are obtained of the use of tuberculin testing, S19 vaccination and milk recording in different types of herd and in different areas.

12.20. YATES, F. (1959). Methods of sampling the population. Contribution to: Immunological and Haematological Surveys: Report of a Study Group. *World Health Organ. tech. Rep. Ser.* no. 181.

Suitable methods of sampling human or animal populations are described. It is suggested that for many immunological and haematological surveys it is preferable to select typically contrasting areas, instead of attempting to cover the whole population.

12.21. YATES, F., LIPTON, S., (SINHA, R. & DAS GUPTA, P.). (1959). An exploratory analysis of a large set of 3 × 3 × 3 fertiliser trials in India. *Emp. J. exp. Agric.* **27**, 263–275.

The Rothamsted electronic computer was used to make a combined analysis of 238 single replicate 3 × 3 × 3 trials on rice, done in the State of Bihar, India, in the 1956–57 crop season. The 3 blocks of each replicate were on 3 separate fields in a village; this had little effect on the estimates of the interactions or experimental error. The experiments attained satisfactory accuracy and showed good responses to N and P, and smaller responses to K, with little interaction between the factors. There were considerable variations in response from thana to thana. The responses showed little correlation with the soil classification (clay, loam or sandy).

12.22. (YEO, D.) & SIMPSON, H. R. (1959). The effect of repeated insecticidal applications on a natural tsetse population. *Bull. ent. Res.* (In the press.)

Using the mathematical model of a tsetse population previously described (*Biometrics*, **14**, 159–173, (1958)), the effect of insecticidal applications is examined and the numerical results obtained are discussed.

Field Experiments

GENERAL PAPERS

13.1. GARNER, H. V. (1959). Fertiliser responses and optimum dressings. *J. Inst. Corn Merch.* **7**, 39–43.

13.2. GARNER, H. V. (1959). The oldest experiment in the world. *Discovery*, **20**, 296–301.

An account of Broadbalk Field, Rothamsted.

Woburn Experimental Station

15.1. THOROLD, C. A. (1959). Methods of controlling black-pod disease (caused by *Phytophthora palmivora*) of *Theobroma cacao* in Nigeria. *Ann. appl. Biol.* **47**, 708–715.

No trees resistant to black-pod disease were found within the local population of Amelonado types, but resistance may occur among a wider range of varieties.

Satisfactory control of black-pod was obtained with copper fungicides, applied with either hand-sprayers or a power-sprayer. The monetary return depends on yield level, rather than on disease incidence or on spraying costs. It is recommended that spraying should be done when the potential yield is 12 or more pods per tree.

Dunholme Field Station

General Papers

16.1. Adams, S. N. (1959). Sugar beet fertiliser experiments in 1958. *Min. Agric. Sugar Beet Res. & Educ. Comm. Pap.* 528.

16.2. Adams, S. N. (1959). Present views on sugar beet manuring. *Brit. Sugar Beet Rev.* **27**, 111–113.

16.3. Adams, S. N. (1959). Manuring next year's sugar beet. *Brit. Sugar Beet Rev.* **28**, 77–78.

16.4. Byford, W., Cornford, C. E., Dunham, E. C. W., Dunning, R. A., & Hull, R. (1959). Sugar beet disease investigations, 1958–59. *Min. Agric. Sug. Beet. Res. & Educ. Comm. Pap.* 527.

16.5. Hull, R. (1959). Spraying sugar beet to control virus yellows. *Brit. Sugar Beet Rev.* **27**, 114.

16.6. Hull, R. (1959). Virus yellows was decreased by spraying. *Brit. Sugar Beet Rev.* **28**, 24.

16.7. Hull, R. (1959). Spraying controlled aphids and yellows. *Brit. Sugar Beet Rev.* **28**, 62.

16.8. Hull, R. (1959). Beet yellows virus; its transmission and effect on sugar beet. (*In* Report of the sugar beet virus disease committee of the I.I.R.B.). *Rep. 22nd Winter Cong. int. Inst. Sugar Beet Res. Brussels 1959*, 273–287.

16.9. Hull, R. (1960). Sugar beet diseases. Revised edition. *Min. Agric. Bull. 142.*

16.10. Hull, R. (1959). Sugar beet yellows in Great Britain, 1958. *Plant Path.* **8**, 145.

Research Papers

16.11. Adams, S. N. (1960). The value of calcium nitrate and urea for sugar beet and the effect of late nitrogenous top-dressings. *J. agric. Sci.* (In the press.)

28 experiments on sugar beet in 1956–58 compared the effect of ammonium sulphate, calcium nitrate and urea applied to the seedbed before sowing at rates which supplied nil, 0·6 and 1·2 cwt. N/acre; also 0·6 cwt. N/acre applied at the end of June.

Average responses in sugar yield were low, 0·6 cwt. N/acre being enough to give maximum sugar production. The heavier nitrogen dressing increased the yield of tops.

Calcium nitrate and urea raised sugar yield as effectively as ammonium sulphate. No fertiliser damaged germination, and urea containing 4·5% biuret used for top-dressing in 1956 caused no damage. Calcium nitrate and, to a lesser extent, urea produced more tops than ammonium sulphate.

Nitrogen in the seedbed raised sugar yield as effectively as a split dressing. Leaching of nitrogen in a wet summer is therefore not important to sugar beet. Late nitrogen, on the other hand, never harmed sugar production if some had been given to the seedbed.

16.12. Baker, P. E. (1960). Aphid behaviour on healthy and yellows virus-infected sugar beet. *Ann. appl. Biol.* **48**, 2.

Myzus persicae, M. ascalonicus, Aphis fabae and *Aulacorthum* species, when caged on sugar-beet leaves in the glasshouse preferred yellows virus-infected leaves to healthy ones; they chose those with the strongest symptoms, on which they bred more rapidly and lived longer than on green leaves. *M. persicae* behaved similarly on whole plants in the glasshouse. The previous

host influenced the aphid's preference. Differences between the multiplication rates of aphids on healthy plants in inbred sugar-beet varieties were eliminated or reversed by infection with yellows virus.

Spraying healthy plants with either sugar solutions or hydrolysate of casein increased the multiplication rate of *M. persicae*, but much less than did virus infection.

16.13. Gibbs, A. J. (1959). Docking disorder. *Plant Path.* **8**, 93–94.

Docking disorder of sugar beet has symptoms similar to acid soil injury, but occurs seasonally on sandy soils with pH value above 6·5. It seems not to be caused by a pathogen but by unusual physical or chemical condition in the soil.

Soil Survey of England and Wales

17.1 Avery, B. W., Stephen, I., Brown, G. & Yaalon, D. H. (1959). The origin and development of brown earths on Clay-with-flints and Coombe deposits. *J. Soil Sci.* **10**, 177–195.

Field investigation of the origin and development of three brown-earth (sol lessivé) profiles was supplemented by mechanical and mineralogical analyses and micromorphological studies. Two profiles, representative of the Batcombe and Winchester series, were on Clay-with-flints and the third, of the Charity series, on a Coombe deposit.

Particle-size distribution and petrographic data strongly suggest that all three soils are derived in part from loess. The Charity is interpreted as an autochthonous profile formed on Head of chalky and flinty detritus mixed with loess by solifluxion, whereas the Batcombe and Winchester are two-stage profiles, formed on composite (non-uniform) parent materials resulting from the superficial incorporation of loess with the truncated or redeposited remains of previously weathered horizons with rotlehm and/or braunlehm fabrics derived from Chalk and Eocene beds in varying proportions, weathered in Tertiary or interglacial periods and rearranged by peri-glacial agencies. Clay-with-flints *sensu stricto*, e.g., in the Winchester subsoil, has distinctive physical, mineralogical and micromorphological characteristics, and appears to have originated by sub-surface solution of the Chalk and illuvial accumulation of clay mainly derived from overlying deposits.

The land-surfaces concerned have probably been subjected to at least one alternation of periglacial and temperate conditions after the addition of loess. Hence the extent to which either profile reflects the influence of the contemporary environment is not readily assessed, but evidence is adduced that the upper horizons of each profile bear the impress of similar pedogenic processes, including eluviation of clay-size material and acidic weathering leading to the accumulation of vermiculite, modified in the Winchester by the effects of erosion and soil creep.

17.2. Crampton, C. B. (1959). Analysis of heavy minerals in certain drift soils of Yorkshire. *Proc. Yorks. geol. Soc.* **32**, 69–82.

Comparison of the heavy mineral suites in drift soils over Trias, Permian and Carboniferous rocks near Leeds with those of the underlying rocks suggests that, apart from certain shallow sedimentary soils over Magnesian Limestone, much material in the remaining drift soils was derived from outside the outcrop of the underlying rock. Material from the Magnesian Limestone has been widely distributed in the area, suggesting a slight extension of the Vale of York glacier beyond the Linton–Sutton Kame Belt.

17.3. Crampton, C. B. (1959). Heavy minerals in certain Old Red Sandstone and Silurian limestone of Monmouth. *Nature, Lond.* **183**, 485.

Library

Book

18.1. Boalch, D. H. (1960). *World directory of agricultural libraries and documentation centres.* Harpenden: International Association of Agricultural Librarians & Documentalists.

Publications of the Rothamsted Experimental Station

(*obtainable from the Librarian*)

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INVESTIGATIONS IN THE LABORATORIES. (1957; 6*d*.)
*ROTHAMSTED, 1843–1943: the work and history of the departments. (1943.)

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Catalogue of the printed books on agriculture published between 1471 and 1840, by Mary S. Aslin. (Rothamsted, 1926.)*
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—*Supplement* . . . List of additions since 1940. (Rothamsted, 1949; paper, 2/6.)
Catalogue of serial publications in the Library, 1953. Edited by D. H. Boalch. (Rothamsted, 1954; 17/6.)
Catalogue of serial publications in the West Building Library at Rothamsted (Entomology, Insecticides, Mycology), March, 1956. Edited by D. H. Boalch. (Rothamsted, 1956; mimeographed; 2/-.)
The Manor of Rothamsted: [a history and guide], by D. H. Boalch. (Rothamsted, 1953; 7/6.)
Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted Collection, by D. H. Boalch. (Rothamsted, 1958; one guinea.)

* Out of Print.

Books by Present and Past Members of the Rothamsted Staff

*1911 HALL, Sir A. D. & RUSSELL, Sir E. J. A report on the agriculture and soils of Kent, Surrey and Sussex. London: H.M.S.O.

*1913 RUSSELL, Sir E. J. *The fertility of the soil.* Cambridge University Press.

*1917 HALL, Sir A. D. *The book of the Rothamsted experiments.* 2nd edition. London: John Murray.

*1917 RUSSELL, Sir E. J. *Manuring for higher crop production.* Cambridge University Press.

*1920 BRENCHLEY, Winifred E. *Weeds of farmland.* London: Longmans, Green & Co.

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